Lab in the Building/Building in the Lab?

Pluripotent Matter & Bioinspiration

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Inspired by nature’s principles of efficiency and supported through pioneering collaborations with scientists, architects are programming matter across unforeseen scales of investigation, shaping the frontier of multiscale design. BIOMS research centers in testing material invention in architecture. A quest for shaping pluripotent matter through programming functions. Matter becomes the system for sensing, actuating and regulating multiple functions. BIOMS’ inquiries examines the association of organic and synthetic matter, methods to supplant mechatronics with programmed material sensing and actuation (chemo-opto and/or mechanic) and the integration of live matter as pivotal opportunities for multifunctional building systems. By interfacing the lab into the building and the building into the lab, we can shape a new culture of material invention in design.
Pluripotent Matter and Bioinspiration

With the desire to capture nature’s intelligence scientists pursue establishing multifunctional matter. This material classification refers to substrates whose advantages are greater than the sum of its parts characterized by multiple functions seamlessly integrated (Bar-Cohen, 2011; Vincent, 2012). The potential advantages of materials with programmed capabilities to generate energy, regenerate, respond and adapt to multiple external stimuli with sensitive sensing and actuation with structural efficiency is inspiring architects to study multifunctional matter. Its pluripotency offers a singular and quasi chimeric opportunity to reimagine the future role of building enclosures or the wall (Gutierrez, forthcoming, 2016). Sensing and mechanical responses to environmental inputs can support energy generation, structural resilience, waste regeneration, and self-repair without the need for electricity or robotics, met solely by intrinsic material reactivity. Literature in material science points to leaps in multifunctional matter particularly in the last five years (Haglund et al., 2009; Park et al., 2009; Corr et al., 2008; Yu et al., 2013; Yun et al., 2012; Liu, et al., 2010; Omenetto and Kaplan, 2010; Liu and Jiang 2011; Maspoch et al., 2007; Xie et al., 2012; Dong and Ha, 2012; Sanchez et al. 2013; Yao et al., 2012; Drisko and Sanchez, 2012; Perineau, et al., 2014; Fuentes-Alventosa et al., 2013).

Nonetheless, this frontier still faces critical challenges ranging from multi-objective response calibration and costs, to manufacturing limitations (Nicole et al., 2010). The already puzzling development of multifunctional materials designed from nano scale upwards is aggravated by complex construction parameters challenges (Aizenberg and Fratzl, 2009; Meyers et al., 2008). If accomplishing multifunctional matter in science is challenging for construction even more. By definition any given architectural system must not only respond to multiple objectives, but also comply with other conditions (e.g. aesthetic, cultural socioeconomic, etc.). Multi-objective performance criteria is inherent to advancing material technology in construction and overall design (Gerber and Lin, 2013). Although critically challenging, architects are taking the risk of pursuing multifunctional matter. Through it the very notion of the role of matter within enclosures is put to challenge. Not only can in principle such materials adapt and balance internal and external building flows they are meant to do it through multi-optimization through matter as the system programmed to make inert materials “alive”. Chasing this pluripotency in materials, architects as scientists are turning to nature for principles of integrative efficiency.
Nature provides us with myriad models of efficient exchange between a given organism and its surrounding environment. It designs integrative structures across scales to optimize resilience and efficiency to maximize existence. Nature constructs complex systems with varied compositions, densities, morphologies, and internal and exchange functionalities are built seamlessly across scales. An abalone’s shells’ differentiated strands across scales of organic “beams” and mineral “pillars” provide compressive strength and elastic resilience just as the spider’s web interchange of varying geometries to maximize tensile strength supported by highly efficient coating technologies (Espinosa et al., 2012). The capability to adapt and respond to internal and external stimuli through tailored biomechanical processes is carried through complex structural differentiations across scales.

Scientists and engineers embarked into studying nature for advancing science and technology over twenty years ago (Vincent, 2012). Over two decades of research has rendered major advances in structural efficiency of biomaterials, as well as, innumerable inventions in areas such as bioinspired micro and nano photonics, fluidics and robotics (Bar-Cohen, 2006). The progressive understanding of how natural processes occur and of the structural complexity of biomaterials and organisms has led to an exponential growth in bioinspired science and technology. The path of bioinspiration in architecture has been unsurprisingly less linear. Architects were drawn first to the geometric complexity of natural organisms for formal pursuits. More recently, design explorations have turned into structural optimization, environmental control systems seizing bioinspiration for problem construction and solving (Knippers and Speck, 2012; Kellert et al., 2011; Zari, 2010; Pawlyn, 2011; Vincent, 2009; Mazzoleni, 2013; Badarnah and Kadri, 2014). Yet, another research area in bioinspiration in architecture is surfacing focused on how materials programmed with multifunctional capabilities developed through multiscale design approaches can revolutionize environmental systems. Through integrated principles of architectural design, chemistry, biophysics, and engineering from the nano scale upwards research teams aim to establish multifunctional matter specifically tailored for building systems.

Multifunctional materials are modelled as hybrid networks. The fulcrum of multifunctional matter is design and fabrication crafted seamlessly across scales so various functions are optimized in an integrative fashion. Four vital characteristics of these new materials are of particular relevance to
architects: self-actuation, hybrid responsiveness, energy generation and waste regeneration, designed to perform through scale-specificity. Real-world conditions demand hybrid responses to environmental inputs such as light, temperature, and humidity in constructions. Hence, single-optimized performance is insufficient to meet practical demands. These materials offer the opportunity not only of single responsiveness, but the ability to synergistically generate energy and regenerate waste derived from hybridized material actuation. Material properties and functions depend on scale. The scale-based structural optimization follows the principles of efficiency found in nature. The programmed hybrid networks endow multifunctional matter with distinctive performance means. It is in this capacity that lies the transformative force for revolutionizing future building enclosures.

However, the fabrication of multifunctional materials which involves bottom-up strategies including self-assembly and intercalation chemistry is challenging (Nicole et al., 2010). These fabrication processes demand a synthesis of traditional nano and microengineering fabrication methods. The already complex demands of multiscale fabrication between the nano and micron spans becomes significantly more challenging as designers seek to develop these materials for construction applications. In response, robust interdisciplinary frameworks are critical. The challenges of fabrication depend heavily in computational innovation and inventiveness. Not only are the manufacturing processes digitally controlled and characterization carried through advanced computation, but multiscale simulation itself requires integrative computational platforms. Consequently, establishing bioinspired materials with programmed multifunctional capabilities designed through intersecting nano and microscale science and engineering and architecture demands transformations on multiple spheres of design and computation. It is within this challenging framework that BIOMS research operates seeking the potential of pluripotent matter for a new frontier in the exchange of the wall and the elements.

The Wall, the Elements and Scalability (Bioms Inquiry)

Structural advances and conceptual transformations of the building enclosure or the wall enabled early modern buildings to construct a continuum with their surrounding environments. This very same capacity eventually became affected by contradictions as a result of material technologies which culminated decades later in façades insensitive to orientation and climate (Leatherbarrow, 2009).
Figure 1  Biological inspirations from: (A) lotus plant system; (B) antenna branch of the silk moth (Keil, 1997); (C) biologically inspired Self-Activated Building Envelope Regulation (SABER) including optomechanical sensor/actuator network, smart external moisture-barrier layer, hygrothermal sensor/actuator network (and total integration on membrane of optomechanical sensor/actuator network), moisture barrier, hygrothermal sensor/actuator network, and micro venturi tubes.

Figure 2  SABERs M.P. Gutierrez, L.P. Lee, Simulation/ measurement microventuri tubes based on self-regulation to light, thermal, and humidity input, author and BIOMS team (image by C. Irby).
As Le Corbusier freed the wall from load bearing constraints, he gave architects unprecedented opportunities to inquire relationships between internal and external conditions (Roth and Hildebrandt, 1927). Jean Prouvé’s translation of the façade libre led to curtain wall studies that challenged previous notions of the wall through technology transfer and pivotal cultural and socioeconomic transformations carried with it. Manually controlled devices such as Prouvé’s façade in Square Mozart in 1953 became the tangible expression of adaptability in environmental control systems (Pfammatter, 2008). Yet, as known contradictions and ironies is characteristic to the history of construction, which in this case led to neutral enclosures fundamentally indifferent to surrounding environments.

The turn into transforming façades into intelligent enclosures carried from the latter quarter of the twentieth century up to date has been largely the result of transformations in our understanding of adaptability and resilience in the articulation of the wall and the elements. From Piano’s early light-controlling terracotta tiles to current EFTE pillow systems during this period we broke into this century predisposed to seeking alternative building enclosures that could revolutionize the role of active/adaptable building enclosures. Advances in thin film technologies with capability to generate energy, control ventilation and thermal transmission and advances in simulation platforms and parametric optimization in architecture streamlined a new era of ultrathin functional substrates. This field provided the fertile ground necessary to explore multifunctional materials in architecture carrying with it the complex challenges previously discussed.

**Scalability**

One of the most critical challenges of bioinspiration in the development of material systems in architecture is systems scalability. The initial extraction of fundamental principles from nature largely discussed in literature is far from simple or easy (Vincent, 2009; Mazzoleni, 2013; Badarnah and Kadri 2014). To establish scalable systems in architecture is often even more complex. It requires a cohesive framework for multiscale design, multiscale fabrication and scalable implementation.

To develop fundamental research in material systems in what is traditionally deemed an applied discipline as architecture inevitably confronts multiple obstacles and challenges. Innovation requires a reassessment of research
scales, methodologies and evaluation, cross-grained with design decisions across all its processes of inquiry. Paradigm shifts in building technology calls for problem formulation and solving where inventiveness is interlinked to concrete realizations. Through material invention BIOMS explores new modes of investigation, collaboration, consolidation, and dissemination in the field of building technology. The research carried at BIOMS (bioms.info) is to explore building technology and performance by understanding matter as the system to balance the dynamics between man-made and natural envi-

Figure 3 Detox Tower: Left: Algae/elastomeric membrane (rendering); Right: Algae/elastomeric 3d print model by author. Taken from: DetoxTower- Live Matter Integration (M.P. Gutierrez, 2011, UC Berkeley). Finalist Evolo International Skyscraper Competition, 2011.

ronments. In summary, this approach entails three fundamental shifts. First, synthetic/active, live, and biosynthetic matter function as the sensor and actuator of building systems similar to biological organisms. When matter has embedded intelligence, systems do not need complex mechatronics and display solid reversibility. Secondly, the development of these materials entails the seamless fabrication from laboratory to large scale productions. Nano and micro engineering and science are threaded to the architectural scale. Thirdly, active matter is designed to integrate and balance flows of energy and matter including waste. BIOMS research aims to establish means to resource resources through closed-loop material systems. Creating active matter that can improve the means by which we capture, concentrate and transfer energy, as well as, regenerate waste and water carries programming materials with multiple functions. Such inquiries involve opening new opportunities in multiscale fabrication processes and multi-objective optimization through integrative models from the nano to the architectural scale.
BIOMs material investigations research primarily biopolymers and biosynthetic polymer composites. In fact, biopolymers are the oldest building material. Animal hide, bones, and plants such as straw are known to have been some of men’s first enclosures. Across time these early biopolymers where supplanted with the use of ceramics, metals, and composites such as concrete. Biopolymers became rather rare in the development of new building technologies. During the twentieth century polymers resurfaced in constructions but as synthetic matter. Although most constructions up to date use small amounts of polymers these materials are projected to have an exponential growth in construction (Fernandez, 2012). Synthetic polymers derive primarily from crude oil and gas bearing strong detrimental environmental implications. Yet, they are proven excellent media for sensing and actuation capabilities due to the affordance to program such functions primarily in elastomers (Brochu and Pei, 2010; Wilson et al., 2007; Meng and Hu, 2010).

Programming non mechanical sensing and responsiveness in thermoplastics and thermosets has also proven highly efficient in recent decades (Mallakpour and Zadehnazari 2011; Bauri et al., 2013; Fernández et al., 2011). Biopolymers while largely restrictive due to durability and weathering challenges in construction are very promising for environmentally sensitive strategies. Yet, with obvious exception of wood and wood composites biopolymers remain as one of the least investigated material families in construction. While largely present in new digital fabrication technologies (e.g. PLA additive manufacturing) the myriad inventions in material science in bio and synthetic polymers have not made way into real-world construction applications with few exceptions. BIOMs research explores new opportunities for biopolymers and biosynthetic integration as medium for programming multifunctional matter in architecture. The span of the research ranges from simple material mixtures where multiscale fabrication enables light and thermal control to photoactive microlenses for radical improvement of light capture and transmission for water recycling and thermal management.

Conclusions

Radical advances in the ability for materials to self-generate and generate from the nanoscale to architecture depends largely in the continuation of robust convergences of architecture, science and engineering. In this process advances in integrative fabrication and multiscale computation is critical (Malkawi and Augenbroe, 2004; Gutierrez, 2011(b)).
In upcoming decades, the research of smart systems is anticipated to advance in two areas: interfacing spaces and multifunctional, high-performance envelopes. For one part, we will witness a growth in the development of interactive spaces that emulate biological models through “neurological responses,” applying high-cognition networks. In parallel, we will continue to pursue material innovation through building skins that can perform multiple and simultaneous operations through self-regulation and generation capabilities. More than a direct transfer from biotechnology, the next decades will continue strengthening convergences of architecture, engineering and biophysics.

To streamline this frontier, architecture will experience major shifts in the development of three main areas: multi-objective simulation models that integrates research from the nano to the regional scale, multiscale digital fabrication for 3d printing materials with programmed responsiveness, and materials with biosynthetic integration from the molecular level to the architectural scale. Key advances can derive from these shifts. For instance, through a more robust synergy between the laboratory manufacturing and larger construction fabrication, architecture can eradicate unnecessary assemblages and joints required for complex building sensors and actuators (Gutierrez, 2008). Through these advances producing smart membranes that use bioinspiration for selectively resourcing energy, water, and materials will be progressively more attainable. Advances in complex cognition, adaptability, self-generation and regeneration, and phased material degradation will be met through this new frontier. By cross-pollinating the lab into the building scale and the building scale into the lab we can not only cement new ground in pluripotent matter, but transform the design agency of material invention.

Aknowledgements


References


Maria Paz Gutierrez is an architect and Associate Professor of Architecture at the University of California, Berkeley. Her research focuses on material invention by integrative nano, micro and building scale design. Gutierrez investigation centres on the role of material invention and craft for addressing critical socioeconomic and environmental urban and rural challenges of the 21st century. Her design explores integrative approaches in material invention pertaining to cultural and biophysical paradigms of natural and human resources particularly in settings under risk.

In 2008 Gutierrez founded BIOMS, an interdisciplinary research group with support from organizations such as NSF, EPA and DOE. Gutierrez is recipient of numerous design and interdisciplinary awards including the 2001 AIA Academic Medal, the 2011 Evolo International Competition Finalist and semi-finalist for the 2014 Buckminster Fuller Award. Her teaching innovation has been recognized both by academia and industry through the 2010 Blue Award, the 2011 Sarlo Distinguished Mentorship Award, and more recently the 2013 Odebrecht Sustainability Innovation Second Prize award (co-advisor). Gutierrez is recipient of the prestigious 2010 National Science Foundation Emerging Frontiers of Innovation Award, a 2011 Fulbright Nexus Scholar and appointed Senior Fellow of the Energy Climate Partnership of the Americas by the US Dept. of State.

Gutierrez’s research has been published in prominent architectural and scientific journals including Science, ARQ Cambridge and her design creations have been displayed in venues such as the Field Museum in Chicago. Her forthcoming book “Regeneration Wall” (Routledge 2017) discusses how our conceptualization and materialization of the wall is bound to radically change from the rise of multifunctional matter. Gutierrez has two provisional patents (lab on wall; elastomer 3d extruder).