Structuring Materiality

Design Fabrication of Heterogeneous Materials

Neri Oxman, Beast: Prototype for a Chaise Lounge, Boston Museum of Science, Boston, Massachusetts, 2008

The cobra combines structural, environmental and corporeal performance into an adaptive material system where density, stiffness, flexibility and translucency in each, determined and specified region independently. It is patterned with five different materials color-coded by elastic moduli, soft and stiff components are distributed according to the user's structural load distribution, soft silicon ‘bumps’ are located in regions of higher pressure.
Nature is demonstrably sustainable. Her challenges have been resolved over eons with enduring solutions with minimal resources. Unsurprisingly, nature’s inventions have for all time prompted human achievements and have led to the creation of exceedingly effective materials and structures, as well as methods, tools, mechanisms and systems by which to design them.

**Structuring Difference: Nature’s Way**

Natural structures possess the highest level of seamless integration and precision with which they serve their functions. A key distinguishing trait of nature’s designs is its capability in the biological world to generate complex structures of organic or inorganic multifunctional composites such as shells, pearls, corals, bones, teeth, wood, silk, horn, collagen and muscle fibres. Combined with extra-cellular matrices, these structural biomaterials form microstructures engineered to adapt to prearranged external constraints introduced upon them during growth and/or throughout their life span. Such constraints generally include combinations of structural, environmental and corporeal performance. Since all biological materials are made of fibres, their multifunctionality often occurs at scales that are nano through macro and typically achieved by mapping performance requirements to strategies of material structuring and allocation. The shape of matter is therefore directly linked to the influences of force acting upon it. Material is concentrated in regions of high strength and dispersed in areas where stiffness is not required. It is a well-known fact that in nature, shape is cheaper than material, yet material is cheap because it is effectively shaped and efficiently structured.

The image of the architect as form-giver has for centuries dominated the profession. In most cases, structural strategies are addressed by way of post-rationalisation in support of the building’s utility captured by spatial properties. In this light, material selection and application are dependent on structural systems. Such views emphasise the hierarchical nature of the design process with form being the first article of production, driving both structural and material strategies. Frank Gehry’s architecture provides many such examples. Steel and glass possess significantly different structural and environmental properties which relate to significantly different performance requirements. Diversity is achieved by sizing rather than by substance variation, and it is typically mass produced, not customised. As far as material structuring is concerned, in the artificial world, especially in the construction industry, one property fits all. Can nature’s ability be emulated in the design of the artificial?

**Form First, Structure First, Material First: New Materialism**

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**In her (nature’s) inventions nothing is lacking, and nothing is superfluous.**

Leonardo da Vinci
Neri Oxman, Carpal Skin: Prototype for a Carpal Tunnel Syndrome Splint, Boston Museum of Science, Boston, Massachusetts, 2008

Left: Physical model of prototype. Material distribution models simulating a range of potential scenarios in the ratio between soft and stiff materials. The charts are computed as a computational unidirectional assignment to construct the 3-D glove. 

The patient’s distribution of pain allows limiting central and lateral bending motions locally and relieving pressure on the median nerve as it acts as a soft tissue-reshaping mechanism.

Opposite bottom: Detail illustrating the distribution of material properties as a function of geometrical constraints. The custom-fit property distribution functions built into the glove allow for passive yet consistent pulling and stretching simultaneously.

Variable Property Modelling (VPM): Chaise-Performative (Boston Museum of Science, 2009)

A single continuous surface acting both as structure and skin is locally modulated to provide for both support and comfort. This design for a chaise longue corresponds to structural, environmental, and corporeal performance by adapting its thickness, pattern density and stiffness to load, curvature and skin-pressured areas respectively. The technical objective was to introduce a quantitative characterisation and analysis of VPM as it is applied to a tiling algorithm using Voronoi cell tessellation.6

Stiffer materials are positioned in surface areas under compression, and softer, more flexible materials in surface areas under tension.7

Variable Property Analysis (VPA): Carpal Skin (Boston Museum of Science, 2009)

Similar to the manner by which load or temperature can be plotted and computationally optimised to fit their function, physical pain may also be mapped in the design and production of medical assistive devices such as pain-reducing splints. Carpal Skin is a prototype for a treatment glove for carpal tunnel syndrome. The syndrome is a medical condition in which the median nerve is compressed at the wrist, leading to numbness, muscle atrophy and weakness in the hand. Night-time wrist splinting is the recommended treatment for most patients before going into carpal tunnel release surgery. The main problem with current glove solutions is their lack of customised features in relation to the patient’s distribution of pain. Carpal Skin is a process by which to map the pain profile of a particular patient – intensity and duration – and distribute hard and soft materials corresponding to the patient’s anatomical and physiological requirements. The relative distribution of softer and stiffer materials across the glove’s surface area allows limiting central and lateral bending motions locally in a highly customised fashion.

Variable Property Fabrication (VPF)

Currently, there exists no rapid prototyping technology that allows for a continuous modification of material properties such as strength, stiffness, density and elasticity as continuous gradients across the surface and volume area of a functional component. Such variations are usually achieved as discrete changes in physical behaviour by printing multiple components with different properties and distinct delineations between materials, and assembling them only after the fabrication process has been completed. Such processes result in material waste and lack of functional precision. Variable property fabrication aims at introducing a novel material deposition 3-D printing technology which offers gradation control of multiple materials within one print to save weight and material quantity while reducing energy inputs. The result is a continuous gradient material structure, highly optimised to fit its structural performance with an efficient use of materials, reduction of waste and the production of highly customised features with added functionality.

Materials are the New Software

Since its emergence in the 1960s, computer-aided design (CAD) in its many transformations has afforded the designer an almost effortless manipulation of shapes generally detached from their fabrication in material form. Such processes promote the application of material subsequent to the generation of form. Even when supported by high-fidelity analytical tools for analysis and optimisation, these processes are predominantly linked to geometrical manipulations in three dimensions. The work presented here calls for a shift from a geometric-centric to a material-based approach in computationally enabled form-generation. Variable property fabrication of materials with heterogeneous properties across a wide array of scales and applications holds a profound place in the future of
design and engineering. The ability to synthetically engineer and fabricate such materials using VPF strategies appears to be incredibly promising as it increases the product’s structural and environmental performance, enhances material efficiency, promotes material economy and optimises material distribution. Among other contributions, material-based design computation7 promotes a design approach through digital fabrication of heterogeneous materials customised to fit their structural and environmental functions. The practice of architecture is at last reawakening to its new role as (a) second nature.1

Notes
7. Material and mathematical studies were carried out in collaboration with Professor Craig Carter and Professor Lorna Gibson from the Department of Materials Science and Engineering at MIT.
8. 2010, MIT patent pending.

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Neri Oxman, Raycounting, Museum of Modern Art (MoMA), New York, 2007, opposite bottom: Raycounting is a method of rendering form by replacing the intensity of light with information about light trajectories. The design is created by assigning link parameters to each point on the surface. The computation calculates the intensity, position and direction of one, or multiple, light rays starting or ending in a given environment and assigns local curvature and material stiffness values to each point in space corresponding to the reference planes. The light direction and structural stiffness are employed for areas requiring structural stiffness as defined by the designer.