



Contents lists available at ScienceDirect

Computer-Aided Design

journal homepage: www.elsevier.com/locate/cad

Editorial

Material ecology



The world of design has been dominated since the Industrial Revolution by the rigors of manufacturing and mass production. Assembly lines have dictated a world made of standard parts framing the imagination of designers and builders who have been taught to think about their design objects and systems in terms of assemblies of parts with distinct functions. The assumption that parts are made of single material and fulfill predetermined specific functions is deeply rooted in design and usually goes unquestioned; it is also enforced by the way that industrial supply chains work. These age-old design paradigms have been reincarnated in Computer-aided Design (CAD) tools as well as Computer-aided Manufacturing (CAM) technologies where homogeneous materials are formed into pre-defined shapes at the service of pre-determined functions.

Inspired by nature, a new design approach has recently emerged called *material ecology* that aims to establish a deeper relationship between the design object and its environment. The key to this approach is the realization that the environment and the design object interact through multiple dimensions and a spectrum of environmental variables. A simple analysis would show that the dimensionality of environment space is much larger than that of conventional design space. This *dimensional mismatch* leads to and results in an *ecological mismatch* where design objects do not quite fit in their respective environments. Material ecology aims to bridge this gap by increasing the dimensionality of the design space through multifunctional materials, high spatial resolution in manufacturing and sophisticated computational algorithms. In doing so, a holistic view of design emerges that considers computation, fabrication, and the material itself as inseparable dimensions of design which results in objects that are ecological from the outset.

The papers included in this Special Issue are authored by research groups from around the world and introduce a suite of biologically inspired digital fabrication tools, techniques, and technologies enabling designs that have a profound connection with an environment.

Kristensen et al. (ETH, Zurich) introduce a novel fabrication method combining slip forming and digital fabrication for concrete structures. In this additive fabrication process a robotic arm is implemented to form the concrete while it hardens, eliminating the need for the complex custom milled formwork and enabling the reuse of the mold over multiple extrusions thus offering greater efficiency and control.

Reichert et al. (ICD – Institute for Computational Design, Stuttgart) propose a new approach to the design and construction of material-based sensing and actuation. The authors focus on

autonomously responsive architectural systems that can adapt to environmental stimuli through hygroscopic material properties. In this framework, all functions are integrated into a single material. Inspired by plant mechanics, the research focuses on hygroscopic actuation in plants as a model for passive, autonomous and materially embedded responsiveness.

Ahlquist et al. (University of Michigan) present a digital framework and software environment for the computational design of geometrically complex pre-stressed form and bending-active architectures. The authors classify relationships between material composition and functional performance based on topological, environmental, and material constraints. Physical models are evaluated by deploying spring-based simulations combined with finite element methods. Amongst the case studies is a banana leaf stalk, which demonstrates intriguing structural combinations of high bending stiffness and low torsional stiffness.

Schleicher et al. (ITKE – Institute of Building Structures and Structural Design, Stuttgart) focus on the challenges and opportunities associated with the design of kinetic structures. The authors find inspiration in flexible and elastic plant movements for kinetic design. Using computational modeling and simulation techniques they reveal motion principles in plants and integrate the underlying mechanisms in flexible structures. Acquired knowledge on bio-inspired kinetic structures is applied to the design of a flexible shading device for doubly curved facades.

Pottmann et al. (TU Graz, Austria) offer an overview of architectural structures composed of or related to polyhedral cells. The authors provide a conceptual mathematical definition of support structures for polyhedral cell packing. Driven by insight from discrete differential geometry, the authors demonstrate successful initializations of numerical optimization schemes for the design computation of quad-based and hex-dominant meshes.

Duro Royo et al. (MIT, USA) introduce a computational approach and software environment for the generation of segmented and articulated armored surfaces that negotiate between functions of protection and flexibility. Modeled after the ancient armored fish *Polypterus senegalus* and through extensive simulations, the authors illustrate structure-to-function relationships of natural bio-armors and emulate these findings in the design of a multi-scale computational model called *MetaMesh*.

Doubrovski et al. (MIT, USA and TU Delft, The Netherlands) present a voxel-based computational method and workflow for

digitally fabricating custom prosthetic sockets. At the heart of this approach is the Bitmap Printing method enabling additive manufacturing of bitmap files embedded with high-resolution data. Beyond local variation in material stiffness, the authors implement variation in transparency and index of refraction in order to incorporate pressure-sensing elements integrated into the socket for performance evaluation.

Burry et al. (RMIT, Australia) review a series of projects exploring complex relationships between environmental boundary conditions and computational methodologies for form finding. The authors argue for the importance of mixed analog and digital media in the early stages of design. The projects demonstrate the integration between sustainable design evaluation software with arduino-based responsive architectures to enable real-time feedback between the environment, hardware devices, the modeling environment and the material system.

The ideas and principles behind *material ecology* inspired the need and generated a framework for innovation in computational form-generation, multifunctional materials and digital fabrication. These approaches in concert will enable the expression of *material ecology* across product and architectural design scales.

Neri Oxman, Ph.D.*

Associate Professor,
Sony Corporation Career Development Professor,
Media Lab, Massachusetts Institute of Technology, United States
E-mail address: neri@mit.edu.

Christine Ortiz, Ph.D.

Dean for Graduate Education,
Morris Cohen Professor of Materials Science and Engineering,
Massachusetts Institute of Technology, United States

Fabio Gramazio

Professor,
Architecture and Digital Fabrication, Department of Architecture,
ETH, Zurich, Switzerland

Matthias Kohler

Professor,
Architecture and Digital Fabrication, Department of Architecture,
ETH, Zurich, Switzerland

* Corresponding editor.