Multifunctional Structures and Materials: the Ultimate Biomimicry

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Multifunctional structures and materials
The more conspicuous examples of biomimicry are superficial
Multifunctionality is a significant fundamental trait of the bio-realm
- Examples
Multifunctional structures are the ultimate biomimicry
- Not so popular – why?
Application Example
- Conductive Plastic & Additive Manufacturing
Definition

Multifunctionality
• Imparting one or more necessary system functions to components of a system that are typically only passive mechanical structures
  ▪ Without negatively impacting strength and weight properties
• Eliminates the need for discrete components required to perform the same function
• Results in minimized system SWaP and design/manufacturing complexity, and opportunity for additional payload (function)

Multifunctional Structures
• A physical structure with multifunctionality

Multifunctional Materials
• A material can either be viewed as a structure itself or a component which enables multifunctionality in structures
Multifunctional Structures and Materials

Mechanical Suitability at Minimum Weight

- High electrical conductivity
- Low loss
- High power handling
  - signal, RF, power
- Impact resistance
- Self-Healing
  - weapons
  - space debris
  - construction handling
- Low thermal expansion
  - antennas, optics, structures
- EM management
- Radiation hardness
  - enclosures, hulls
  - RF cables
- RF/EO Management
  - high energy protection
  - energetic enhancement
  - hulls, survivability, other
- Fatigue resistance
- Cold welding resistance
  - gimbal wiring, small radii bends, structures
- High thermal radiation
- Low heat capacity
  - radiators
- Customizable thermal conductivity
  - thermal straps
  - insulation
- Low reflectivity
  - stray light management
- Mechanical damping
- High stiffness
  - enclosures, structures, bays, boxes, isolation
- Energy Storage/Generation
  - structural batteries/capacitors
  - power scavenging
- High Ops Temperature
  - structures, engines

Disruptive Technology
= Reduced size, weight, power, design/manufacturing complexity
Mission

- Enabling new applications through developing and integrating new and conventional materials into multifunctional composites and materials for reducing size, weight, energy consumption, and manufacturing complexity; and increasing performance, ruggedness, and survivability.
The “Veneer” of Biomimicry

Flies Like a Bird
(UMD/ARL Robo Raven)

Walk Like a Mule
(BD/DARPA-ARL BigDog)

Swims Like a Fish
(USN GhostSwimmer)

Move Like a Bug
(Kladitis Microrobot)
In order for a system to:

- Fly like a bird
- Walk like a mule
- Swim like a fish
- Move like a bug

Multifunctional structures and materials must *pervade* the system

.... possibly with no exceptions
Examples of Multifunctional Structures in Nature

With Multifunctionality

Without Multifunctionality
The Human Body

- **Bones**
  - Scaffolding/Frame
  - Impact shielding
  - Chemical synthesis (blood cell production...)
  - Chemical storage
  - Self repair
  - Information transfer

The Human Body

- **Muscles**
  - Mechanical actuation (many purposes)
  - Mechanical stabilization
  - Cushion
  - Heat generation
  - Chemical processing
  - Aesthetics
  - Self repair
  - Information transfer

Examples of Multifunctional Structures in Nature

The Human Body

- **Arteries and Veins**
  - Hydraulic containment
  - Active flow control
  - Self repair
  - Information transfer

- **Organs: Liver**
  - Chemical production
  - Chemical storage
  - Chemical synthesis
  - Self repair
  - Information transfer

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The Human Body

- Skin
  - Mechanical cover
  - Radiation shielding
  - Chemical-Bio shielding
  - Filter
  - Chemical synthesis
  - Thermal management
  - Aesthetics
  - Self repair
  - Information transfer

Examples of Multifunctional Structures in Nature

The Human Body

• Fat
  ▪ Mechanical cushion
  ▪ Thermal insulation & shielding
  ▪ Energy storage
  ▪ Nutrient storage
  ▪ Aesthetics
  ▪ Chemical production
  ▪ Information transfer

Examples of Multifunctional Structures in Nature

So ....

- Nature has the most optimum system designs
- HIGHLY Multifunctional Structures and Materials proliferate these natural systems
- Multifunctional Structures enable the conspicuous traits we admire and mimic
- Enabling Multifunction Material to “mimic” may be Carbon

Therefore ....

- To go even further in the area of biomimicry, we should make development of multifunctional structures and materials **TOP PRIORITY**
Challenges to Multifunctionality

- **Design (verb) Complexity**
  - More difficult to think about – engineers are lazy

- **Maintainability Requirements**
  - Maintenance nightmare – until self-healing is realized

- **Manufacturability**
  - Manufacturing infrastructure not yet suited for this – based on singular/serial components/functions

- **Short Term Gain**
  - Not as sexy as the veneer functions
  - Needs more development

- **Cost**
  - Development, Maintenance, Industrial Capital, etc.
What multifunctionality should be pursued first with most potential for impact?
• Integrated electronics

What parallel bottoms-up manufacturing technique would be most amenable to make a highly integrated multifunctional structure?
• Additive Manufacturing

Conductive Thermoplastic + Fused Deposition Modelling (FDM)
Multifunctional FDM

Base Thermoplastic
Polymer Chemistry/Synthesis
Nano-Fillers
Treatments

Small Batch Compounding (100s g)
Screening Panel & Specimen Fabrication
Material Property Measurement
Compound Downselect

Large Batch Compounding (~50 lbs)
Filament Extrusion
Pelletized Filament

0.071" Filament Returned from Stratasys
Printing Parameter Optimization
Printed Parts
Material Property Confirmation
Printing Problems?

Ship to Stratasys
Material & Process Refinement

shaping the technology of tomorrow

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New thermoplastics enable multifunctional FDM structures
- World’s first FDM printed wire connectors, CNT wires, wire harnesses, and other structures
  - Space qualified and flying now
- Two material printing of Conductive & Nonconductive Thermoplastics (conductor & insulator)
  - Enables all passive electrical circuit elements
  - Enables functions only requiring passive elements
Passive elements are not enough for full electrical function – What is still missing are

• p-n junction: enables diode, varactor, and transistors
  ▪ rectification, variable capacitor, amplification, switching
• battery: enables power supply
p-n junction is the heart of transistor action

Diode & Varactor (p-n junction)
Multifunctional structures and materials

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  • Should be top priority

Challenges

Integrated Electronics
  • Conductive Plastic & Additive Manufacturing
We Are...

Flexible
Responsive
Agile
Solution Driven
Innovative
Customer Focused
Objective
Value Oriented

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