Digital Bio-Inspired design:

Integrating natural principles in computational design

Theory of Design Computing
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I. Introduction
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Particular interest for this study:

Providing a descriptive account of twin biologically inspired design processes, *problem-driven* and *solution-based*, and highlights the application of solution-based approach in bio-inspired computational design.
2. Background
Background

**Biological systematization** (Greg Lynn’s reversal of D’Arcy Thompson’s “On Growth and Form”)

**Structural analysis and remodeling of force systems** (Frei Otto, catenary and branching structures)

**Translation of natural form into architectural geometries** (Peter Pearce’s node systems, Buckminster Fuller’s geodesic domes)
Understanding the underlying logic, mathematics and chemistry of nature's forms

The **mathematical concepts of nature** can be used to generate architectural form.
3. From CAD to Computational design
Critical distinction between Computer-aided design (CAD) and Computational design!
CAD

1. CAD employs the computer as a helpful extension of established design processes based on geometric information: points, lines, surfaces and solids.

2. Form and information are synchronously constructed and conceptually constitute an inseparable entity.

3. Rooted in object-based methods of accumulating information and encapsulating it as explicit as well as symbolic representation.
In this regard

**CAD** has not really changed the way architects design; it has simply
‘**computerized**’ well-established methods of geometric description!
While in the computerization of analogue design techniques information is only compiled and associated,

Computation enables the processing of information in such a way that new information is created.
In summary:

The transition from computer-aided to truly computational design entails a shift from:

(i) Modelling objects to **modelling processes**
(ii) From designing shape to **designing behaviour**
(iii) From defining static digital constructs to **defining computing systems** capable of reciprocal data exchange and feedback information.
5. Twin Processes of Biologically Inspired Design
Biomimicry can happen in three ways:

- inspiration of
- mimicking of (eco)systems

The third one “mimicking of (eco)systems” is called “biomimetic” as a design process typically fall into two categories:
5. Twin Processes of Biologically Inspired Design

• Problem-Based Approach

• Solution-Based Approach
Problem-Based Approach

Top-down approach
Challenge to biology
Technology pull
Problem-Based Approach

- Problem statement
- Search for natural analogous
- Extracting the biological principles
- Representation
- Simulation
- Problem re-definition
- Refine
- Feedback
- Assessment
- Test
- Evaluation, testing
Solution-Based Approach

In this method, inspiration from nature would be applied to an existing area of interest.

In other words, the computational theories innovated based on biological principles can be applied in a design process.

“Bottom-up approach”
“biology to design”
“solution-driven biologically inspired design process”
“biology push”
Computational Theories Based on biological principles

Biological research

Description of Construction

Understanding Principles

Abstract

Finding the Problem

Transfer to Technical Solution
Watson claimed that architecture is not a problem solving, instead it is a process in which designers gradually discover what can be possible.

Thus, in architectural design, nature should have a role to be a source of inspiration to designate what might be possible than a source of answers to the problems.

In architectural design, designer should create opportunities instead of only solving the problems.
6. Computational Theories based on Nature
Inspiration from nature in a computational context leads to form some computational theories based on biological principles.

Developing from 60s to 70s coincident with technological enhancement in electronic devices and hardware
6. Computational Theories based on Nature

- Cellular Automata (1940s)
- Artificial Neural Network (1943)
- Genetic Algorithm (1960s)
- L-systems (1968)
- Fractal (1975)
- Artificial life (1986)
Cellular Automata (1940s)

- It can simulate the **process of growth**
- Mathematical models for very complicated **self-organizing systems** in nature (snowflakes, turbulent fluids)
- Generating organized patterns
Genetic Algorithm and Evolutionary Computation

- Mimic the natural evolution
- Through a natural evolution, a huge set of possibilities is the set of possible genetic sequences and the desired “solutions” are high-fitness organisms

- So the mechanism of evolution can be used in computation search methods.
Genetic Algorithm and Evolutionary Computation
L-systems

- It can model the **growth process of plants** in a simplified way.

The **branching** and **bifurcation** are developed in two steps:

growth (a)
or as
reproduction (b).
There are two transformation rules:

1. \( b > a \)
2. \( a > ab \).
7. Application of Biological Principles in Computational Design through a Solution-Based Approach (bottom-up)
7. Application of Biological Principles in Computational Design through a Solution-Based Approach (bottom-up)

Fibres
Branching Construction (L-systems)
Fibres

Important Properties of Natural Fibre Composites

- They are anisotropic. The material’s structural capacity can be adapted in response to the force’s direction and magnitude.
- They emerge from adaptive growth. New material is located at the position and in the direction where it is needed.
- Organisation and layout. The basic materials of biology are so successful not so much because for what they are, but because of the way in which they are put together.
ICD/ ITKE Research Pavilion 2012:

Exploring the material and morphological principles of biological fibre composites, such as the as a source of exploration for a new composite construction paradigm in architecture.
Three steps of design:

1. Biological Model
2. Transfer of Biomimetic Design Principles
3. Computational Design and Robotic Production
Biological Model: exoskeletons of arthropods
Transfer of Biomimetic Design Principles
Computational Design and Robotic Production
lobster’s cuticle
robotic carbon and glass fibre filament winding
computational design process

Enable a high level of **structural performance** and novel tectonic opportunities for architecture.

Development of extremely lightweight and materially efficient structures.
Conclusion