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Extended Abstract

GASTROPOD SHELLS: QUANTITATIVE BIOMIMICRY FOR ADAPTABLE STRUCTURES

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Abstract:

Biomimicry—the design concept that draws sustainability ideas from Nature's time-tested patterns and strategies—has been applied to challenges in many engineering disciplines, but rigorous applications of quantitative biomimicry to the built environment are scarce. This research studies how biomimicry might be applied to structural forms through a bottom-up approach, where emergent properties are examined to determine the causes of structural form. As an example, this paper investigates the *Turritella terebra* gastropod shell for its ability to adapt to meet increasing performance demands as it grows. Adaptability parameters are explored through a structural engineering approach with the goal of synthesizing this knowledge to create adaptable, environmentally-appropriate structures at the civil infrastructure scale.

Introduction and Background:

Sustainability and *resiliency* have become buzzwords in scientific and engineering communities because their importance is overwhelming, but without *adaptability*, neither of these ideologies can be realized. Our current building design philosophy is predictive—we design based on our assumptions of what loads a structure might need to withstand in its lifetime—but we can never be sure of what unforeseen circumstances will be headed our way. Even obsolescence, the lack of suitability for desired use, is a phenomenon plaguing our built environment. A study in Minnesota found that about 60% of building demolitions are due to obsolescence (*Minnesota Demolition Survey: Phase Two Report, Prepared for: Forintek Canada Corp.,* 2004). By treating our construction waste as resources, an overwhelming 92% of building materials can be generated from renovations and demolitions (*Design for Deconstruction*, 2010). Unfortunately, these valuable materials are going to waste, as most of our buildings have not been designed to allow for the deconstruction and reuse of components. If we can build adaptability inherently into our designs, we can preserve the embodied energy and carbon already invested in these materials. We live in a dynamic era shaped by climate change, urbanization, and transformative information technology, but our infrastructure is ill-prepared to meet both expected and unexpected changes.

Instead of designing buildings according to predicted loads, biomimetic designs have the potential for creating buildings that grow as performance demands increase. By quantitatively examining Nature to determine how it achieves its forms through its functions, this research investigates how biomimicry might be applied to building structures through a bottom-up approach. Specifically, the *Turritella terebra* seashell is studied for its ability to adapt through growth to meet increasing performance demands.

Theoretical Approach:

Turritella terebra are gastropod mollusks (e.g., related to common snails) with long, spiraled shells that grow in height and diameter as the mollusk ages. Through a structural engineering approach, this research investigates which aspects of the shell contribute to its ability to adapt over time. For example, how and where the mollusk naturally deposits material to form its shell can inform how built structures can optimize their initial design to allow for unplanned and unprecedented additions. Moreover, an investigation of how Nature's shells carry loads (e.g., minimizing drag forces due to a streamlined shape, torsional compression like a mechanical spring, etc.) and what types of loads they are optimized to carry can also lead to the development of a design paradigm that draws from its surroundings to make structures adaptable and environmentally-appropriate.

Figure: *Turritella terebra* (photo by H. Zell / CC BY-SA 3.0)

Methodology:

This research examines the adaptability parameters of a specific type of seashell in order to synthesize and apply this knowledge to the built environment through a biomimetic lens for the purpose of adaptable structures. This section outlines the steps taken to realize this objective.

To begin, an in-depth ecological literature review was conducted to better understand gastropods' natural environments, behavior and morphology; Understanding the *Turitella terebra*'s background informs what types of loads it carries, reasons for its growth pattern, and how to quantify its form. The geometric properties of gastropod shells can be simplified and described as a series of equations. Variables that determine the form of the shell include: vertical distance, whorl number, radius of the helico-spiral, and various expansion rates, among many others (e.g., Thompson, 1945;

Raup, 1961; Fowler, Meinhardt, and Prusinkiewicz, 1992). These parameters can then be encoded to create a mathematical model where variables can be adjusted to digitally represent various types and sizes of shells (e.g., Picado 2009). Mathematical models such as these have been expanded into 3D computational models (e.g., Faghih Shojaei et al., 2012; Jirapong and Krawczyk, 2003), and a handful of researchers have even incorporated material properties and applied loads to finite element (FE) models to determine the stress and failure profiles of various shell geometries (e.g., Faghih Shojaei et al., 2012; Sorguç and Selçuk, 2013).

Testing, Validation, and Verification:

In parallel to the computational methods described above, empirical testing of *Turitella terebra* shells will be conducted and resulting data will both aid and validate the FE model. This experimental testing will be designed to identify the shells' limit states, load-bearing ability in different configurations, and material properties. The linearly elastic portion of the material when under stress will be the focus of this research. Experimental strain and displacement data will both be used for model validation.

In addition to traditional structural engineering measurements, this project will investigate how the density of calcium carbonate, the main material component, varies throughout the shell and between shells of different sizes. By studying the material growth between shell sizes, we hope to draw conclusions about the growth patterns of the shell as the mollusk ages. A preliminary study of how spatial density functions are investigated in coral reefs through a biomimetic lens is described in Chen, Ross, and Klotz (2014).

To verify the computational models, the model geometry will be visually evaluated against shell samples along with photographs and scans of shell cross-sections. The parameters identified in initial geometric simplification, such as material thickness, radii of the helico-spiral, and the outline of the generating curve, will be compared.

Parametric Studies for Adaptability:

The objective of this research is to identify the adaptability parameters of the gastropod shell that allow it to meet increasing performance demands as it grows. One way to identify which features qualify as adaptability parameters is to conduct parametric studies. These studies will be applied to both the mathematical and the FE model to explore the effects of both internal (material, geometric) and external (load application) factors on the overall adaptability of the shell. Variable relationships that have significant differences between smaller (younger) and larger (older) shells may reveal sought-after parameters. It will be of interest if this research verifies that the natural morphology of the shell is already optimized for carrying the loads it experiences.

Summary and Conclusions:

Through a structural engineering approach and a biomimetic lens, this research examines the *Turritella terebra* gastropod shell to identify adaptability parameters that allow it to meet increasing performance demands as it grows. This project draws on previous work in ecology, conchology, and architecture as technical guides. Parametric studies of both internal and external factors are conducted through the adjustment of variables in the mathematical and finite element models developed. This work combines existing studies by applying quantitative biomimicry to human-made structures to contribute to the development of a sustainable built environment.

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