Modeling Emergence: Motility Systems for Bio-Inspired Play

Bonnie DeVarco[1] Joseph D. Clinton[2] Melodi Simay Acar[3] Gary Doskas[4]

[1]Buckminster Fuller Institute; devarco@cruzio.com
[2]CIDC Clinton International Design Associates; jclintonds@gmail.com
[3]Kinetikhane Arch & Eng. Ltd. Sti. Istanbul, Türkiye; melodiacar@gmail.com
[4]Hedron Designs, Shrewsbury, MA; gary.doskas@gmail.com

Abstract

We trace the theory and pedagogy underpinning a new class of "X-motiliY Systems – geometric models designed not merely to mimic structural features, but to capture and explore Nature's dynamic, self-generating behaviors. This approach introduces new geometric models that embody the emergent behaviors we see in in biological structures such as seedpods, cells, bacteria, viruses and other natural forms that exhibit motility.

Modeling Emergence

What do we mean by "modeling emergence?" Emergence stems from Latin "emergere," signifying "bringing to light." Emergence can encompass the metaphysical quality of a new insight, or the physical act of a seedling emerging from the soil or spiraling out of a seedpod and into the wind. Modeling serves as a conduit to understand Nature's principles through embodiment—revealing patterns, behaviors, processes, and the intricate interconnectedness that defines life's complexity. By incorporating structural dynamism into the design process, we can create physical models that demonstrate novel behaviors.

Innovation in Education

We have witnessed a growing recognition of the vital role play serves in learning. In the early 20th century, visionaries such as Friedrich Froebel and Maria Montessori pioneered methodologies that profoundly impacted early education. They emphasized the importance of high-quality, self-correcting models, modules, and materials that fostered self-directed play These educational systems comprised individual "sets" designed to engage all the senses, fostering an iterative learning process through hands-on experience. They are constructivist education methodologies that emphasize a concrete-to-abstract understanding – a philosophy rooted in praxis (learning by doing).

Childhood is an innocent stage of pure discovery, when we are captivated by Nature. We may be amazed at the way bubbles float in the air or burst when they touch our fingertips. We may marvel at the geometric shapes of seedpods, or the way seeds spiral down from the trees. One powerful encounter with Nature may leave an imprint that lasts one's lifetime. Some may act on this early impulse in discoveries that occur much later in our lives. Five-year old Albert Einstein was fascinated with the enigmatic movement of the needle in his first compass. This experience propelled him in a search for answers, culminating in monumental contributions to humanity's grasp of the cosmos through his theory of general relativity. Buckminster Fuller's early revelation of the structural integrity of the triangle and tetrahedron came through building with a Froebel "Peas Work" module at age five, an oft recounted story. The experience shaped his visionary designs and architectures for decades.

The enduring impact of play in early education is evident in our built environment. Iconic Froebel blocks have influenced architectural aesthetics, notably seen in the rise of "mid-century modern" style. Architects like Corbusier, Fuller, and Frank Lloyd Wright, who played with these blocks as children, were deeply influenced by their experience in kindergarten, a term coined by Froebel in the 1800s.[1]

Pedagogical advancements in multisensory learning has increased our recognition of the broad range of student learning styles.[2] Gardner's Theory of Multiple Intelligences [3] enlarged our understanding of intelligence. Fresh learning materials and approaches breathed new vitality into the interdisciplinary STEM curriculum by adding art to science, engineering, technology and mathematics: STEAM.[4] doing.

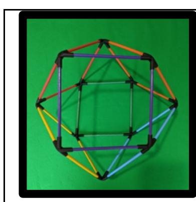
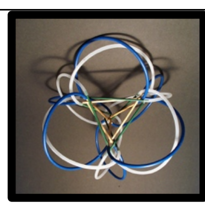
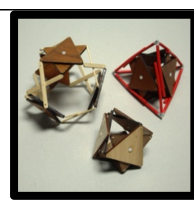
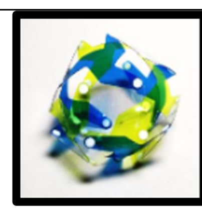
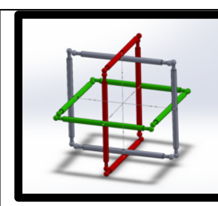
Playing with motility structures can inform new bio-inspired architectures. Biomimicry, as described by Janine Benyus, involves understanding natural forms, processes, and ecosystems.[5] To grasp Nature's complexities, we must engage all of the senses through modeling systems that exhibit mobility, resilience, and transformation. Tensegrity systems with these properties have already influenced architectural design for space exploration (projects such as NASA's Super Ball Bots). Architects Norman Foster and Amey Kandalgaonkar often draw inspiration from Nature to design both space structures and terrestrial shelters.

Whole Systems Design: from Static Polyhedra to Dynamic Energy Systems

Hands-on exploration of polyhedra has led to a profound evolution in our understanding of form. From Archimedes' derivation of truncated Platonic solids, to the cage structures depicted by Renaissance artists, to the transformative concepts encompassed in the energetic architectures of the newest generation of expandable structural systems, as seen in the works of Fuller, Hoberman, Clinton and others, we can see a rich landscape of architectural innovations informed by the historical evolution of polyhedra.

Although we can showcase static architectures in the physical world and display dynamic structures on our computer screen, the challenge arises when attempting to manifest these qualities in physical models endowed with mobility. Our methodology involves engaging all senses through praxis–learning by doing, vividly illustrating the dynamic interplay between equilibrium and transformation.

We derive inspiration from Buckminster Fuller's *jitterbug*, a transformational polyhedral vector system that introduced many new properties to the known families of polyhedra.[6] Fuller pioneered a whole systems modeling methodology that led him to the design of modular, mobile shelter systems and energetic forms. He considered structure "a complex of energy events." Both vectors and vertices are dynamic energy centers. He termed his multi-scale design process to be "micro-incisive and macro-inclusive." Fuller's long friendship with Ludwig von Bertalanffy, the father of General Systems Theory, further reinforced his whole-to-parts orientation. A 1995 study of the cowpea chlorotic mottle virus, using the rotation-translation transformations exemplified in the "jitterbug concept is only one of the countless other fields of discovery that increases our understanding of biological morphology.

 Jitterbug	 Anti-Ambi-Structor	 Chiral polyhedra	 Juno's Spinner	 X-motilitY System: Melodi's Cube
R. B. Fuller	Don Briddell	Joseph D. Clinton	Juniche Yananose	Melodi Simay Acar Gary Doskas

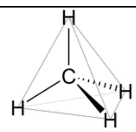
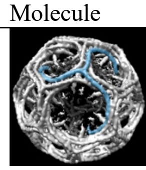
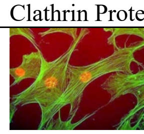
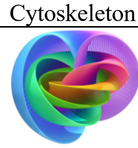
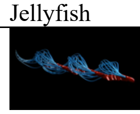
Stability to Mobility to Motility

Digital modeling methods have advanced through visualization technologies, physics engines, and immersive experiences through VR, AR, and XR. Yet, they still fall short of replicating the experience of embodied play with physical models. Chemists, biologists, virologists, and other researchers employ a combination of 2D, 3D, and 4D geometries to unravel the mysteries of structure on both micro and macro scales, they face a crucial limitation: the absence of the multisensory engagement that embodiment provides. Despite our technological mastery, the tactile, sensory-rich experience of physical interaction remains unmatched, offering insights that transcend mere visual representation.

X-motilitY structures are energetic through torsion, twist, hinging, and other dynamic mechanisms. We began with the simplest structure in the X-motilitY system, "Melodi's Cube," designed by Melodi Simay Acar. These models are spontaneous and their motions are self-generative. They represent a paradigm shift in design, evolving and exhibiting unexpected behaviors driven by geometric memory and iterative sequences, mirroring motile phenomena in Nature. Spanning from two to twelve degrees of freedom, these structures emerge as dynamic, "energetic" systems that exhibit a wide range of behaviors.

Table 1 shows the evolution from rigid structures to X-motilitY systems in six stages and their counterparts in Nature. The integration of algorithmic structures, as demonstrated by Gary Doskas' Simulator program, offers insight into the orchestrated sequence of changes within these systems. It may unveil some of the behaviors of complex adaptive systems.[7]

Table 1: *Comparison of structural models: rigid, semi-rigid, tensegrity, transformative, motility*

Characteristics of Systems	**Example Models**	**Natural Structures**	**Design Principles/Properties**
1. Rigid	Triangle, Tetrahedron,	 Methane Molecule	**Stable structures:** Fixed lengths, fixed areas, fixed directions
2. Semi-Rigid	Knotworks, Woven structures	 Clathrin Protein	**Nonrigid, soft structures:** bendable, twisting, anistropic, embedded curvature, chirality
3. Tensegrity	Tensegrity models by Fuller, Snelson & others	 Cytoskeleton	**Tensile structures:** tension & compression, material constraints, efficient use of materials
4. Transformational	Jitterbug, Tetrahelix Simulator	 Hopf Fibration	**Shape transformation:** geometric constraints (includes twist) removing constraints (expansive, contractive, growth); unique symmetries at different stages
5. Kinetic, Foldable	Hoberman sphere	 Jellyfish	**Adaptable:** incremental, deformable, foldable, reversible, mobile, disposable), rotation, translation, motor-based, weaving, linkage systems
6. X-motilitY	Melodi's Cube Doskas' Simulator,	 Sperm	**Motile:** Structural system based on torsional equilibrium with the ability to transform simple external forces into directed motion.

The "I Wonder" Modeling Process

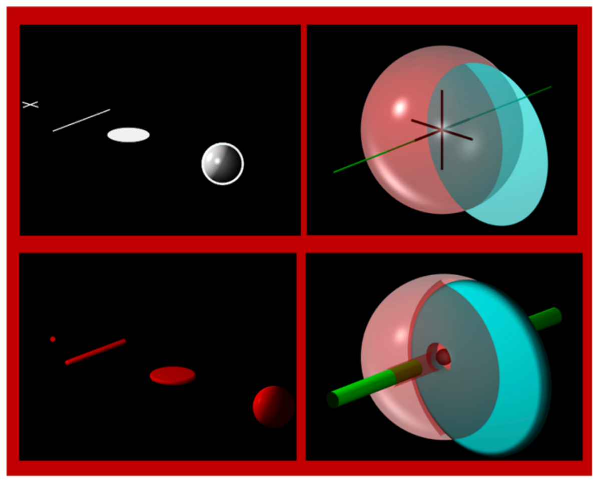
"… The world we see – the visual world – is so clearly 'out there' that it can come as something of a shock to realize that somehow the whole of this world is tucked away in our skulls as an inner representation which stands for the real outside world. It is difficult and unnatural to disentangle the 'perception of a scene' from the 'scene itself'' but they must be clearly distinguished if seeing is to be understood."[8]

Geodesics expert, Joseph D. Clinton introduced the "I Wonder" modeling process as a journey of curiosity and discovery.[9] He draws inspiration from his personal interactions with Buckminster Fuller and his own application of comprehensive anticipatory design science. This iterative process prompts new questions and "what if" scenarios. This dynamic form of praxis takes us from concrete to abstract, abstract to concrete. Dynamic modeling nurtures our innate curiosity and childhood wonder, sparking new insights. The "I Wonder" process creates a feedback loop between the physical attributes of the materials employed in modeling and our cognitive processes.

The mathematical language we use suggests a point is only a position in space. If given length and direction it moves into a line, and if the line is moved parallel to each other they describe a plane. Similarly, if many planes are moved parallel to each other, a solid is described.

In the language of physics, points, lines, planes and solids cannot share a common position in space without interference with each other. They must accommodate one another.

The motion that modeling needs for emergence begins at the center of thought as a stimulation of the senses in the form of "I Wonder." Around the center are four spheres of influence of the eye of "I Wonder." The dilations within the system describing the "I Wonder" process starts by defining the interactions needed or not needed within each of the four spheres of influence.



Summary and Conclusions

The importance of play in early education and the appeal of polyhedra is a focus for understanding a new class of motility structures that emulate the behaviors we witness in biological life. Constructivist education methods demonstrate the power of model-making for multisensory, self-directed, hands-on exploration.

References

[1] N. Brosterman. *Inventing Kindergarten*. NY: Harry N. Abrams, 1997

[2] B.Prashnig. *Learning Styles and Personalized Teaching Action*. Network Continuum, 2006

[3] H. Gardner. 1983. *Frames of Mind: The Theory of Multiple Intelligences.* NY: Basic Books, 1983

[4] J. Maeda. "STEM + Art = STEAM," *The STEAM Journal: Vol. 1: Iss. 1, Article 34*, 2013

[5] J. Benyus. Handbook online: *A Biomimicry Primer*. AskNature.org p.4-5, 2011

[6] R.B. Fuller, E.J. Applewhite *Synergetics – the Geometry of Thinking*. p. 356-359, 1975

[7] G. Doskas. *Geometric Transformations of the Tetrahelix*, 2022 https://youtu.be/O1gP-hFw-34?si=7wCufTWq3J-podXU]

[8] J. Frisby. *Seeing: Illusion, Brain and Mind*. Oxford: Oxford University Press, p. 9, 1979

[9] E.S. Popko, C.J. Kitrick. *Divided Spheres: Geodesics and the Orderly Subdivision of the Sphere* 2nd Edition. C.R.C. Press. p. xv to xxi, 2021