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This paper will discuss the use of complex systems in analyzing biological precedence of self-organizing, self-stabilizing and emergent phenomenon. The use of complex biological systems will be used to define relational models that avoid issues of scale. Scalability (the ability to traverse scales) will be presented as a relational construct through the use of scope, not scale. The analysis of biological formation and organization as a relational model defined by scope will be presented as a generative in forming design strategies and solutions and will be illustrated in four undergraduate-level architecture studio projects.
1 Designing with Relational Generatives

There is a rising confluence between emergence and self-organization through complexity as a generative framework for design. This framework thwarts classical authoritarian and dogmatic organizations and formal logic; however, new questions concerning the role of the designer have taken shape. Among them:

- How do we begin to bound, manipulate, or otherwise allow the general to guide the specific?
- How do we utilize the phenomenon of emergence rather than only observe it?
- How do we move from the mechanistic to the systematic?

In current design thought, complexity is viewed to be a régime of responsive, inclusive and subsequently, an accumulative disassociated phenomenon. In other words, a self-organizing system in which the rules that govern the local traverse scale through recursion and the global through abstraction. This assumes a classical understanding of scale; one in which a reliance on complexity through addition or simplification through reduction is needed to bridge the gap between scalar levels. It also assumes that complexity generates the emergence of self-organization.

Complexity in this mechanistic world view is akin to complication where “more is more” not “more is different” (Anderson 1972). If however, we consider scalar logic as being a condition of “scope”, we discover that scalar logic is inherently a bounding operation that shifts the criteria by which information is observed, comprehended, judged and utilized (Ryan 2006). Those strategies, forms, and performances that are appropriate at one scale can become increasing ineffectual, hierarchical, complicated and/or possibly irrelevant other scales. Issues of material performance, operable dimensional parameters, and time become increasingly problematic when designers use biology as a constructivist generator of objects and environments of various scales and complexity (Anderson 1972).

However, biology provides evidence that scope defined as the formation of wholes traverses the issue of scale by providing relational models that can be measured through performance criteria rather than solely transposing formal or dimensional information. Stuart Kauffman’s work with Boolean networks devised such a model that operates as a “scale free network” but is scalable (Kauffman 1993). Kauffman’s work found a separation of scale from scalability. This happens in two steps: 1. The concept of the whole as being that which exhibits emergent phenomenon, self-organizing or not, removes dimensionality from the definition of scalability. 2. It also defines the whole as no longer being reducible to a collection of parts in which one part “communicates” with an adjacent, but in fact suggests “conditionality” where communication happens across scales (Ashby 1962). In this way, the ability to communicate information across wholes defines scalability as a construct of relations within or between scopes and scale as a construct of dimensions.

Scale in the classical Newtonian context refers to spatial linear transformations of dimensional information. The reliance on recursion and reduction alone to bridge the gap between scales (dimensions) fails to engage scope (wholes) and does not readily allow for the exploration of relationships crucial to self-organizing and stabilizing systems. Conceiv-
ing of complexity as a product of the emergence of unpredictable attributes within a whole that is not present within other wholes allows us to model relationships as instances of emergence. The relationships formed between wholes govern the creation of ensamples. The ensample is scale-less; it is however, bound by scope. In fact ensample is a relational model and does not favor complexity over simplicity, but instead forms increased complexity as new whole states with unpredicted attributes emerge through the communication between states.

This paper will examine four student projects that investigate design as a relation-based endeavor. One project adapts the framework of scripting to traverse scalar complexity, bridging the disjunction between bottom-up and top-down design philosophies. In effect, this creates a top-down feedback loop to bottom-up structural formations, organizations, and articulations. In essence, it is a relational model.

2 Instructing with Relational Generatives

The design studio began by grappling with the task of developing performance criteria which could gage complexity as a product of self-organizing and self-stabilizing biological systems. The creation of scopes or wholes from which performance criteria could be based allowed us to equalize differences across a variety of scales, formations, materials, organizations, and causal stimuli. To achieve this, every student not only analyzed how and why these systems tend toward states of self-organization and stabilization, but to identify extractable and translatable relationships that could guide the development of their own relation-based designs.

The next task was to understand these performance criteria in ways that allowed translation and transposition of these attributes into relational schemas. Understanding was gained by testing the viability of these abstracted and extracted relationships by generating one-to-one scale constructions.

The last task was to create a self-organizing and self-stabilizing system that given their relational design precedent could in fact respond to a variety of desires, inputs, and formal and organizational pressures. Students were assigned four initial problems to solve with their system.

- Three-Dimensional Propagation: How can these systems define three dimensions and enclose space?
- Edge Conditioning: How does the system accommodate limiting, bordering, and connecting situations?
- Directional Morphology: How does the system accommodate continuously changing or discrete directional changes?
• Self-intersection: How does the system respond to intersecting with itself, duplication, or its multiple? And at what scales?

These questions were not mutually exclusive and students found that the solutions to one problem led to new ways of approaching the remaining questions. These questions were conceived of as a means to which each system—now translated from real world examples into proto-relational models—could be tested with concrete spatial and architectural problems. At this point, the models which contained a multiplicity of possible formations and organizations were asked to generate actual structures. The questions prompted students to further their design as a system rather than design through addition or simplification to solve individual problems. In the end, we were looking for the development of robust systems derived from relational models.

3 Four Student Projects

Each of the following student projects represents four different approaches to relation-based design through the exploration of generative relational models. Projects 1 to 3 follow the above steps and culminate in built constructions at various scales of actualization and produced a variety of qualities. Project 4 developed the translated and extracted relational systems into a set of scripts that retain these relationships and produced parametric properties without dictating a specific solution. These scripts were then developed and tested through the design of a building enclosure.

3.1 Project 1: Cumulative Stability

Project 1 focused on designing an interdependent system of structured units in which loading of the system at either specific points or uniformly produced a stronger link between units. The term units is used loosely as the model formed a variety of wholes defined by performance manifolds rather than number.

The goal was to isolate structural failure locally and a limitation of the material, and not the system. This subsequently allowed for a focused investigation of material performances within this given interwoven structural system. It also allowed for the development of a construction logic that utilized the properties of the studied materials in both novel and inventive ways.

The concept of system strength through interdependency was established by studying the geometry of carbon atoms as they form solids and understanding how its structure is manipulated in two and three dimensions to create efficient structures (Figure 1). This project also investigated the formation of organisms that produce self-similar units such as the radiolarian to create adaptive systems of growth. The radiolarian produces parametric relationships between parts which are not identical, but rather deviations of ideal geometries. Each deviation bridges parts and absorbs the difference between separate parts that allow a change in direction, intersection and border, thus answering many of the questions of robust systems design.

This investigation brought to light the adaptive nature of parametric formations. The final construction consisted of a two-dimensional part that formed a three-pointed pin-joined unit that when interlaced with two additional units formed a 9-pointed self-stabilizing unit. This final unit could propagate in multiple trajectories and gained system-wide strength though patterning around spherical voids (Figure 2). The patterns that emerged were the product of implied spatial organizations formed between unit scale levels, not present at any one scale level.

3.2 Project 2: Flexible Mating

Project 2 studied the layering of geometric systems with complex force dispersion and suppressing capabilities to generate a relationship between the patterning structural members and performance. This project began by studying geodesic geometries, tensegrity, tensioning patterns, and a layering strategy used by the Venus Flower Basket (VFB). The VFB is a deep sea creature that uses a flexible and lightweight silica-based exoskeletal lattice to resist expansion from internal tensions, deformations from current flow, crushing from water weight, and torsional collapse within its cylindrical body, while maintaining.

The project translated the VFB’s flexible and layered lattice into a performative relation-
ship of compressive and tensional layers with specific weaving patterns to allow for con-
trolled movements and stability. This project also studied the geometric principle behind
geodesic spans and enclosures, where a system of adaptive parametrics was developed
to linked discrete geodesics together within a certain percentage of difference. A relation-
ship between the number of member types and the difference in geodesic complexity was
established. (Figure 3). These linking geometries were then abstracted into a set of geo-
metric rules that responded to the base geodesics in question. From this exercise and the
combination of layers and patterns as a separation of performance developed from the
VFB research, a controlled flexible mat was designed to accommodate distortion in three
dimensions given a set of parameters (Figure 4). Limits of distortion the system accepted
could be predicted given a set of compressive and tensional members and a set of vertices
and layering patterns.

The project’s assumptions about construction and propagation were studied in proto-
types at various scales and with multiple compressive and tensional materials. The final
construction was built as a series of units whose geometry was rigid in one plane and flex-
ible in another. Layered together, the units allowed for distortion to be tested. Once a de-
sired configuration was found rigidity was achieved by linking units through tension mem-
bers with specific linkage patterns (Figure 5). The final construction allowed for iterative
investigation with a single construction rather than multiples.

3.3 PROJECT 3: TESSELLATING SURFACE VOLUMES

Project 3 took articulation derived from a number of tessellation patterns (a mathemati-
cal description of cellular surface tiling) for point dispersion along a surface and tested it
against closed and self-intersecting surfaces to form a three-dimensional relational-based
tessellation generation process. This process which could have been automated into a
scripting language created hexagonal self-similar shapes that articulated surfaces and/or
subdivided surfaces to form skeletal systems of enclosures.

The tessellation process articulated a given geometry into limited ranges of deviation
and adapted those limits to material properties either as a skeleton or surface structural
logic. This articulation established a parametric that eliminated the need to design each
unit manually.

First, a surface was subdivided into a series of points, the midpoint between any two
determined the maximum or minimum length required for a given material. By applying
two converse tessellation techniques, an average range was found through which a border
points and center points were determined. Any change in the position of one point rever-
berated through the system creating deviations in the base hexagonal articulations. Any
surface could then be articulated through the input of various criteria. The final calcula-
tions were tested iteratively forming unpredictable structures that conformed to a desired
scope of quantities and qualities. The process was repeated with changes in variables,
limits, and surfaces to which it was applied, and in this way, not only produced iterative
solutions, but iterative applications as well. Each instance of its application translated the
desired relationships into specific dimensional data which could be output with common
CNC technology.

The final construction of this project consisted of a compound-curved wall manufac-
tured by translating the vertices of a three-dimensional computer model into continuously
structured hoops (Figure 6 & cover). The investigation into surface tiling yielded a pro-
cess that could generate specific geometries based on a set of relationships and any given
surface. This project gave insight into the possibilities of forming manageable emergent
solutions.

3.4 PROJECT 4: SCRIPTING PERFORMANCE

Project 4 was an exploration into scripting relational criteria to produce performative so-
lutions to design problems. A search for a framework by which we can make relation-
based decisions for form and structure tempered an exploration into biological and adap-
tive growth sequences. Models like L-systems established examples for the translation of
adaptive growth sequences. This project explored the logic of these models by scripting a
few relationships (Figure 7):
3.5 APPLICATION TO BUILDING PROJECTS

The last stage of the studio was to apply these relational systems to architectural projects. We will look at one project—Project 4—that was carried to this stage.

This project continued the expansion of a responsive and relational structuring script for compound surfaces by testing the script in the design of an architectural project. The scripts became a structuring schema that responded to natural meteorological phenomenon based on location and orientation through a further refinement of surface articulation as a derivative of the initial script that defined structural relationships.

The system designed for a specific surface condition was then tested against various surface conditions (flat, ruled, compound, intersecting, folded, and chamfered) to determine its potential failure points. Failure in the script was defined by two criteria. The first criterion occurred when the script failed to produce a structural system and articulated surface. This may have been due to a number of problems with either the script itself, the computational program or the definition of the base surface being tested. The second criterion occurred when the script produced irrational structural organizations and formations. These included:

- An inability to sub-divide, reconnect, and further articulate the entire surface.
- The production of anomalies in members or surfaces. For instance, those whose dimensions were not within an acceptable predetermined range or whose deviation from a predetermined mean were not of an expectable percentage or multiplier.
- The production of unwanted redundancies.
- The production of astructural conditions—ones that did not adhere to the initial relationships established through the study of self-organizing and self-structuring systems for complex form generation.

These were not failures in the sense that they were defined as undesired, unaesthetic, or unpredictable formations. Redundancy, anomaly, incompleteness, simplicity, or complexity were in and of themselves acceptable given that they adhered to the relational criteria which established the script. Questions of its phenomenological value and proportional and dimensional elegance were important. However, these criteria were enacted from a set of successful iterations as a way of insuring that the final building reached a certain performative threshold. The goal was to preempt any subjective limits imposed on a system until it was better understood in terms of the systems’ formal and performative potential.

Next, the scripts were tested against surface typologies. These included surfaces with compound curvatures, ruled surfaces, flat surfaces, chamfered and filleted surfaces, and self-intersecting surfaces. The test defined the limits of the scripts’ logic when applied to surface typologies not originally designed for. The tests served to reintegrate data into the workflow developed to create the original script. Further exploration of the system was conducted through the application of the scripts on a building skin. A number of specific performances were designed for including structural growth, airfoil surface shaping, and articulation of curved surface enclosures (Figures 8 & 9).
The findings from surface type testing created a feedback loop that reinforced the relational constructs of the design premise. The formation of a feedback loop was essential in creating an emergent process of design.

4 Paths & Models

If we consider complexity in biological processes as being relational in practice such as Kolmogorov’s scaling law which can be translated into dimensions on a case by case basis, but which operates relationally, we begin to understand that when analyzing and appropriating processes and formation in biological complex systems, classical mechanistic notions of scale, whether local or global cease to be linear, discrete and dimensionally relevant (Ball 1999). Issues of scope and conditionality become a more relevant way to utilize emergent and self-organizing properties inherent in many biological precedents allowing us to reconceptualize the frameworks through which we design. The value in instructing from this pedagogical position is that ideas such as novelty and failure become instances of emergence, a catalyst for design, and not problems or events to be avoided.

By taking Ashby’s “conditionality” to mean a sphere of communication coupled with the concept that scope (instances of emergent properties) define a whole or an ensample of wholes we have superseded the problem of translation across scales. The path to scalability and complexity is through information communication not just adjacently but across wholes and relational models become generators of design solutions.
5 Contributions
Design work presented in this paper was contributed by undergraduate students from the University of Texas, School of Architecture from the 07/08 academic year. They include: Paul Gay—project 4, Kai Pedersen—project 2, Sergio Saucedo—project 3, and Natalia Ziemian—project 1.

6 References