Form Force Matter

INVESTIGATING FORM-ACTIVE SYSTEMS THROUGH ANALOG MACHINES AND PHYSICS-BASED SIMULATION

ABSTRACT

Form-active Systems offer an intuitive means of gaining direct and tangible knowledge for addressing architectural design problems with degrees of complexity typically beyond our capacity or desire to engage as designers. With these systems as a mechanism for research, we may establish a rich territory in which form, force, and matter are inherently imbricated in their conceptual domain. Furthermore, if we approach this conceptual terrain with an understanding that the elements of these systems exist along a continuum between the real and the virtual, we may incorporate methods and techniques in the form of analog machines and physics-based simulation from architecture’s peripheral fields of structural engineering, physics, and computation. This paper presents an applied research framework undertaken in a continued sequence of seminars whereby Form-active Systems are analyzed for their performative characteristics, synthesized for operative design strategies, iteratively prototyped across scales, and redeployed within the context of a multi-story installation.
First, architects cannot handle large scale problems, for they are too complex; second, architects ignore small scale problems, for they are too particular and individual (and to them, trivial) (Negroponte 1969).

In his seminal essay, ‘Toward a Theory of Architecture Machines’, Nicholas Negroponte suggests that the scale and complexity of any design problem is a limiting factor in an architect’s decision and desire to engage a given problem. He goes on to posit that “architecture machines,” implemented through computation, are a way to expand the architect’s capacity to address large-scale problems thus liberating him or her to be able to do more of what he or she desires. By hybridizing the opportunities within a technological approach such as Negroponte’s with a conceptual approach that focuses on the related concepts of form, force, and matter, we may establish a rich territory of investigation in which the system of inquiry is intuitively conceptualized and our capacity to engage complex design problems is expanded.

Form may be understood as the associations that exist between entities. “Form is not so much the form of things as the forms between things” (Allen 2009). This definition of form opens the concept to systemic inquiry in which forms can just as easily be understood as shape as the immaterial relationships present between a shape’s constituent elements. While the concept of form is here generalized and open, force may be understood in the most straightforward sense as any influence causing change, specifically change of direction, magnitude, or shape. Lastly, matter may be defined as anything that has properties of substance: mass, volume, elasticity, etc. If we loosen the typical definition of matter as directly equated to substance, it can exist at any position along a continuum of the real and virtual so long as it possesses physical properties. With these three concepts, specifically loosened in their definition, we may establish a territory for investigation that is precisely defined but not overly constrained.

In the simplest case, a design solution addressing the interrelated concepts of form, force, and matter would consist of an architectural configuration, a structure and corresponding space, capable of resisting gravity under its own self-loaded materialization. While the verification of a system’s capacity to stand has long been the domain of polymaths and structural engineers, one can trace an innovative lineage in the history of architectural design in which material is engaged directly and utilized for its capacity to reconfigure under pressure into stable forms. Whereas an architect’s model relies primarily upon the convention of scale for representative purposes, the model of the engineer utilizes the physical properties of a material system to arrive upon a stable structural form which is optimized for the distribution of static forces. Engaging such a model requires the conception of form, force, and matter as interrelated and active agents within the process of stabilization. Historically, the extensive use of material models within engineering can be traced to the 18th century and specifically to the work of Robert Hooke, who utilized suspended chains and the corresponding funicular curves to verify the structural integrity of Christopher Wren’s dome at St. Paul’s Cathedral. Funiculars, derived from the Latin for rope, are shapes in which the “structure in the ideal case coincides precisely with the flow of stresses” (Engel 2007). Funicular curves are easily demonstrated to be effective in the context of post-design verification, specifically because of the coincidence of material and force. Due to the intuition that can be quickly derived from this coincidence, funiculars can be further instrumentalized as a system for design generation when engaged within the design process itself. The effects of such an engagement can be easily read in the work of Antoni Gaudi (Figure 1), from Chapel Quell to the Sagrada Familia, the extensive research of Frei Otto and the Institute for Lightweight Structures, and more recently in that of Michael Herzog and Achim Menges. In all cases, material models are the evidence of a design approach that foregrounds discovery and conceives matter under force as a necessary and active agent in the configuration of forms.

2 Form-active Systems

Form-active structure systems are structure systems of flexible, non-rigid matter, in which the redirection of forces is effected through particular form design and characteristic form stabilisation (Engel 2007).

Drawing from the heritage and accumulated knowledge of funicular shapes, Form-active Systems, as defined by Engel, extend the behavioral characteristics of rope and chain models to a broader set of stable system-level configurations. In such systems, the imbricated nature of form, force, and matter are maintained but the conceptual and technical territory through which we may deploy them is expanded, foregrounding an active material engagement displaying effective design characteristics. While the defining characteristic is the stabilization gained by the interaction of matter and forces, Form-active Systems display additional characteristics of order, effectiveness, and scalability once stabilized.
2.1 ORDER, EFFECTIVENESS, SCALABILITY

Form-active Systems are capable of negotiating and calculating stable configurations that begin in either hierarchical or heterarchical states precisely because the elements of the system are under pressure and consequently in constant feedback. Additionally the hierarchical and/or heterarchical character of the stable result is ostensible even though the initial state may not be. This may be most clearly articulated when one looks at the weighted thread models of Chapel Guell by Gaudi. We perceive order but aren’t required to understand the relationship of the parts of the system before weight is applied.

Beyond their capacity to achieve stabilization, Form-active Systems are effective in that they are able to negotiate both intrinsic and extrinsic forces while maintaining efficiency and robustness. In the ideal case, matter and forces are coincident tending the system towards structural optimization of forces that exist within the system including self-load as well as externally applied loads. Such efficiency is maintained after the removal of any element within the system as the remaining elements will reconfigure in response.

Form-active Systems are inherently polyscalar in their material and organizational definition. They are capable of stabilizing consistently independent of a transformation in dimension, although such a change requires a reciprocal transformation of some aspect of the system if certain characteristics are intended to remain consistent. Material, dimensional, and quantitative properties perceived at one size can be easily intuited to exist at another; however, the transformation of the effects present at the initial size will not maintain the same intensity, thus foregrounding questions of design by requiring a direct engagement of the production of effects across the transformation.

As with funiculars, Form-active Systems are primarily defined by the stabilization they acquire over time and the coincidence of the force within the configuration of the resulting form. This material coincidence guarantees that such systems are direct and intuitive. Approaching design research primarily through material models results in direct consequences to the configuration, thus the manipulation by the hand has instantaneous and proportional effects on the system (Figure 2). In this manner, the hand, eye, and mind are simultaneously activated and the researcher gains direct and haptic knowledge of the system. Additionally, this directness does not necessarily equate to linear causality in the Form-active System. While their behavior is ostensible and intuitive, they are capable of finding forms that are not pre-determined. “Effects cause changes, rather than only causes having effects” (Spuybroek 2008). The non-linear capacity of Form-active Systems makes them particularly fruitful for in-depth applied research that may investigate complex architectural problems yet their intuitive nature makes them an extremely productive and accessible design tool. Working with such systems requires no acquired experience or knowledge, despite the fact that one may achieve complex and effective results very quickly.

3 Framework

Through an iterative and lateral trajectory of research that utilizes methods of analog machines, simulation, and prototyping, we may establish a framework that relies upon thinking and doing across mediums while incorporating computational techniques that include physics-based simulation.

3.1 ANALOG MACHINES

Analog machines require a hands-on engagement and, through real time feedback, offer an opportunity to quickly capture haptic knowledge of Form-active Systems (Figure 3). In the vein of Frei Otto’s Institute for Lightweight Structures, the initial properties of the Analog Machines are explicitly defined and analyzed for their capacity to both find equilibrium and create productive architectural characteristics (Figure 4). Matter is understood as active, reconfiguring when the tension forces acting on the machine are manipulated. The research identified three main types of Form-active Tension Systems to investigate: membranes, cable nets, and elastic networks, and a catalog of operations for each system were developed through minimal holes, knotting, and topology respectively.

3.2 SIMULATION

The initial state and applied forces of the Form-active Tension Systems investigated were then analyzed through force diagrams (Figure 5). By applying physical properties such as mass and elasticity to the geometric elements, the diagrams moved from discrete to physical geometries and consequently could be developed into virtual Form-active Systems. Technically, the diagrams were made live (Figure 6) through the physics engine Kangaroo for Rhino and Grasshopper. In this digital context, the research
undertaken through analog machines served as the control for developing consistent behavior of the simulated system. The virtual first equaled the real in all conditions of dimension, elasticity, and resulting curvature while the visual and haptic knowledge gained from working with the analog version informed the extension of the initial analog studies within the virtual environment (Figure 7).

3.3 INSTALLATION

As a means of testing the effectiveness of the research, a multi-story installation was designed collectively by the participants of the seminar. Strategies and behaviors of each of the initial Form-active Systems researched (Figure 8) were hybridized into a larger tensile structure sited within two and a half stories of an interior stairwell. The system was composed of braided rope which established a new boundary and means of connection within the space, a variable pattern of elastic rope loops, and digitally fabricated acrylic connecting clips. Iteratively developed prototypes served as the means to test the structural integrity, ease of assembly, and subsequent production of effects. Upon arriving at a final designed and simulated configuration (Figure 9), the final installation was parametrically “unrolled,” creating one-to-one cut templates for each unique loop component and assembly keys for orchestrating connections of the clusters of loops (Figure 10). The final assembly consisted of nine-hundred elastic loops, twenty-four hundred acrylic clips of three types, and a network of edge cables connecting the system to points along the stairwell, allowing for incremental tensioning of the entire system (Figure 11). The set of techniques developed enabled a fluid conceptual and technical navigation between the real as given, the virtual as simulated, and installation as the embodiment of redeployed real/virtual design strategies (Figure 12).

4 Conclusions

The research presented in this paper demonstrates the potentials for, and intuitive engagement with, applied research of Form-active Systems within the context of architectural design. Furthermore, when coupled with a conceptual territory between form, force, and matter and investigated through a framework that establishes a continuum between the real and virtual, the research and subsequent installation illustrate how operative design strategies may be developed and redeployed in varying contexts. Scale, as the critiqued convention for architectural models, becomes the mechanism for focusing on design issues within the transformation of a Form-active System. When undertaken through the incorporation of techniques and technologies from the fields of engineering and physics, the research described here demonstrates a productive methodology for design within applied and pedagogical contexts.

Acknowledgements

We would like to thank the Pratt Institute School of Architecture for continued support; specifically to Erika Heinrichs and Jason Lee for the opportunity to develop this research; and to the students for their dedication and effort: Wilson Cheng, Joseph Kim, Chelsea Mailler, Eri Semerzakis, Paul Scrughiam, and Gillian Shaffer.

References


