SOFT SYSTEMS

Rethinking Indeterminacy in Architecture as Opportunity Driven Research

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Abstract. The research projects in this paper examine the notion of soft systems relative to machine induced material consequences. It asks, how might we integrate processes and methods which leave tolerances for indeterminacy and flexibility into design and construction? The two projects outlined investigate change of state materials paired with automation strategies, focusing on additive processes with thermally induced material configurations and programmable matter with magnetically controlled formations.

Keywords. Robotics; 3d printing; digital fabrication; automation; indeterminacy.

1. Introduction

Sanford Kwinter defines a soft system as one which is “flexible, adaptable, and evolving, [...] complex and maintained by a dense network of active information or feedback loops [and which] is able to sustain a certain quotient of sensitive, quasi-random flow” (1993, pp. 211). In other words, a system is soft when it is driven by dynamics, responsive to change, and comfortable with indeterminacy. In the 1960’s soft systems were under investigation in many disciplines, including philosophy and the sciences, and represented a common thread of speculation. In architecture at this time, projects such as the Fun Palace by Cedric Price and Ville Spatiale by Yona Friedman, were investigating the conceptual approaches to soft systems as design opportunities (Bhatia 2012). While Price was more interested in intelligent reconfigurable spaces which would allow for a multiplicity of use, Friedman saw indeterminacy as an opportunity for individual choice and expression.

Before these soft infrastructural proposals in architecture, John Ruskin suggested alternative ideas of soft systems in architecture through his term savageness. Piotrek Swiatkowski in his assessment of this Ruskinian notion, explains the
builders of Gothic cathedrals, often worked in the harsh climates which made construction particularly difficult; he writes, “They frequently made mistakes. Sometimes the craftsmen corrected them, but more frequently they just let them be. Such mistakes, in fact, did not have a negative impact on the beauty of the constructions. To Ruskin, these mistakes are even a central aspect of the beauty of the cathedrals. According to Ruskin the buildings are more beautiful because such savage details are markers of who the workers are, where they live, and what they do.” (2014, pp. 43). Ruskin’s characterization of savageness suggests soft systems resultant from flexible stonework methods which allowed for imprecision, chance, and response to change. This stochastic craft based method along with the 1960’s projects, question the long accepted Vitruvian notion of firmitas and suggest potential for embracing indeterminacy in architectural design and construction.

In computation today, soft systems are integrated through computational approaches which leave tolerances for imprecision and uncertainty (Köppen 2016). In soft computing, the word soft draws on the meaning related to adaptability. However, soft in other contexts can also pertain to a material quality, meaning malleable or reconfigurable, or relate to a geometric property meaning curved or rounded. The subsequent collection of research projects engage in softness, by exploring soft not only as a computational idea, but also as a material and tooling approach for appropriating technology in design. The evaluation criteria and essential questions for the research include the following: How might indeterminate processes be integrated into architectural design and construction and what design opportunities might arise from no longer being constrained by existing methods? What opportunities might arise from developing an automated system which does not rely on direct translation, but instead operates and predicts outcomes within a range of potential results? How might designers work with automated processes which mediate between material volition and the rigid order of computational control?

2. Indeterminacy and Fabrication

Consideration of material properties is essential to the discussion of manufacturing processes (Schodek 2005). In order to achieve desired effects and design intentions, new digital manufacturing techniques are emphasizing the role of material investigation (Kolarevic 2008). Thus, this research examines indeterminacy relative to materials and machines processes which leave room for chance or imprecision. Within the current discourse of soft systems relative to material properties and tooling production, the research is precedent by Roxy Paine’s automated sculpture makers (1996-2001) and Anish Kapoors 3d printed concrete (2009). The two material based research projects outlined draw on ideas of indeterminacy in change of state materials by looking at thermally induced 3d printing and magnetically controlled formations. By using unconventional materials, the research seeks to discover ways of developing instrumental rules around material properties and behaviors. It asks, what are the ways design research can promote a greater understanding of materiality relative to fabrication processes not only to allow us to better employ traditional materials, but also to embrace the possibilities present
by new materials? How can we rediscover materiality through experimentation and computation?

2.1. ADDITIVE PROCESSES WITH CHANGE IN STATE MATERIALS

The Hydronic Printer is a material and tooling research project which uses a temperature induced change in state material paired with a hydronic cooling additive system. The water based casting system relates to the Fluid Cast research conducted at the Design Research Lab at the Architectural Association School of Architecture (2011) and WX, a wax sculpture machine, produced by masters students under the instruction of Andrew Witt at Harvard Graduate School of Design (2013). This work differs by exploring the automation of the liquid flow rate relative to the casting process. The method for the research involves a series of melted wax material tests extruded into a container while the water level rises within it. The initial material studies inform the tooling parameters for both water rate and position of wax deposition. These studies also inform a base knowledge of the physics and chemistry of wax formation through hydro induced cooling.

The setup involves heated liquid wax controlled with an extruder and a container with variable water level controlled with a water pump and Arduino (figure 1). The constants include: wax temperature upon exiting the extruder, water temperature, and the rate of wax extrusion. The variables include: water flow rate and extruder position and path. An optimum speed in the pump relative to the extrusion rate results in a cylindrical 3d wax print. When deviating from the pump optimum speed, the width of 3d printed wax changes. The results show that as the water pump speed increases the width of the print becomes more narrow and as the speed decreases the width of print widens (figure 2). The variable water pump speed tests inform a documented taxonomy which shows how the overall geometry of the print changes based on the change in water fill rate (figure 3).

The experiments try to mediate and find an equilibrium between the indeterminate qualities of material behavior and automated precision of machine control. The material tests result in a range of figures from stable to fragile and some to points of rupture. A catalog of the material responses relative to deposition and water flow rate translate into a soft computable process where certain target results are predictable and are calibrated to inform tooling development. The outcome is a 3d printer which uses an automated wax extruder controlled with a robotic arm deposited in a water tank with automated water levels controlled with Arduino and a pump (figures 4 and 5). The research team worked to develop an interface using grasshopper plug-ins Kuka PRC for robotic control and Fire-Fly for Arduino. The interface takes in a desired geometry as input and outputs corresponding water fill rates and machine code for the robotic arm which controls the tool path for the wax extrusion. The resulting printer acts as a demonstration of indeterminate material systems paired with automation in order to provide a critique to the current methods of using support materials in additive manufacturing and draw attention to the potential for materials that respond to change in temperature and moisture.
Figure 1. Photographs of research tools and setup including an Arduino controlled water pump.

Figure 2. Diagrams and photographs illustrating the change in wax 3d print width based on the change in water fill rate.
Figure 3. Taxonomy of wax 3d prints showing variations based on water fill rate.

Figure 4. Robotic arm extruding wax into water tank with variable water fill rate.

Figure 5. Resulting wax 3d prints shown at three moments in time as water fills the tank.
2.2. PROGRAMMABLE MATTER

*Magnetic Formations* is a design research project which investigates ideas programmable matter through a fiber reinforced change of state material. It asks, how might a material which is fluid and malleable take on a controlled pattern or form? How might material properties be integrated into the development of tools for fabrication and assembly? Related research includes the projects *Magnetic Architecture* produced by masters students at the Institute for Advanced Architecture of Cataluña (2012), *Matter of Flux* project from Andrew Witt’s Expanded Mechanisms course the GSD (2012), and the work of Self-Assembly Lab at MIT (2014). However, the *Magnetic Formations* project differs by testing the range of possibilities capable within a specific magnetic solution with smooth consistency and ideal fluidity for magnetic pull. The research began with tests of variable amounts ingredients for a magnetic solution to produce a balanced ratio of water, polyvinyl acetate, iron filings, and borax. The polyvinyl acetate is synthetic polymer which reacts with the borax to form a precipitate; the final solution provides an ideal viscosity in order for the solution to move with a magnetic force pulling the iron filings within it. The magnetic solution relies upon the locations, strengths, and movements of nearby magnets to trigger changes in form. The magnetic fields produced from these points initiate the iron filing’s suspended movement within the viscous solution while the remaining ingredients act as a binding medium. Initial experiments demonstrate how the magnets must be place with alternating north and south poles. Figure 6 and 7 illustrate plan and section diagrams of the magnetic solution and the magnet location and polar orientation.

The research method consists of developing a series of challenges to document and record the various configurations of the material and its limits. The challenges were to produce controlled forms including rectilinear geometries, controlled patterns, columns, and walls (figure 8, 9, and 10). In order to test these constraints, instrumentation is constructed around the solution to act as a scaffolding for holding magnets and controlling their toolpath with 5-axis of movement. Once the solution is magnetically moved and formed into its intended formal composition it is held in place until the water evaporates and it fully cures. Integration of electromagnets into the scaffolding also allow for the activation of the magnetic force for formation of the solution and then deactivated to allow for ease of removal once the curing process is complete. The scaffolding can then be removed to isolate the cured magnetic formation. This project also fits within the domain of soft systems as it operates with in a range of tolerances related to the limitations in magnetic pull and material consistency. While the path and location of the magnets are precisely defined, the reaction of the solution is not exactly known due to changes in the distribution of magnetic fillings constantly in flux. While a range of results become predictable through testing, each repeated experiment differs slightly due to these differences in the filling’s location throughout the solution. With the *Magnetic Formations* project the research team accepted these tolerances and subtle uncertainties. By cataloging the distinctions of repeated experiments, the research produces a programmable matter which is predictable with a range of results instead of a specific execution.
Figure 6. Plan diagrams of magnetic solution during formation indicating magnetic pole orientation and location.

Figure 7. Section diagrams magnetic solution during formation indicating magnetic pole orientation and location.
Figure 8. Time based mappings of magnetic solution forming into a square and controlled patterns.

Figure 9. Time based mappings of magnetic solution forming vertically and diagonally as columns and walls.
3. Conclusion

This collection of research projects seeks to uncover the capacity of architecture to engage in stochastic processes and strives to bring ideas of material volition into to the discourse of design. While they are initial explorations of soft systems relative to materials and machines; this area of pure research seeks to inform and encourage larger scale applied research which could be adapted to architectural design and construction. This research asks, how we might imagine a design and construction scenario which is no longer confined to prescriptive material dimensions, but is instead driven digitally controlled stochastic material processes? Integrating soft systems into advanced manufacturing and architecture means perceiving the element of chance not as a hindrance, but as an opportunity. However, within this polemic lies the potential to not only rethink indeterminacy in relation to materials, machines, and geometry, but also to ask how design guided by the computation might allow for the study of indeterminacy in regards to human behavior as Price and Friedman suggested. It is within this immense range of potential applications that soft systems provide a way for framing and pursing optimistic alternatives for appropriating technology in design and developing opportunities for rethinking indeterminacy in architecture.
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References
