Soft Computing in Design

Developing Automation Strategies from Material Indeterminacies

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Abstract. Integrating concepts of soft computation into advanced manufacturing and architecture means perceiving the element of chance not as a hindrance, but as an opportunity. The projects examined in this manuscript explore opportunities for integrating material indeterminacy into advanced manufacturing by pairing a certain degree material unpredictability with the rigid order of machine control. The three projects described investigate three common categories of automated tooling including additive processes, subtractive processes and molding / casting processes. Each project begins with the question, what opportunities might arise from the mediation between material volition and computational control? By embracing indeterminate material results and taking an optimistic stance on chance and uncertainty, which are usually treated as problems rather than values, the intent is to provide ways for automating unique material effects and explore the opportunities for integrating soft computing in design.

Keywords: Robotics, 3d Printing, Digital Fabrication, Automation, Indeterminacy

1 Introduction

Architecture's relationship with instrumental knowledge and indeterminate systems has a long history. From the drawing instruments of the 18th century, such as those exhibited in George Adams's *Geometrical and Graphical Essay,* to the advent of human computer interaction in design seen in with Nicholas Negroponte's foundation of the Architecture Machine Group, instrumental knowledge has played a pivotal role in mechanized and computationally based approaches to design [1]. While we see this history of machine epistemology arising early on in architecture, the capacity of architecture to engage in indeterminate systems finds its strength much later in the 1960's speculative projects, such as Cedric Price's *Fun Palace* and Yona Friedman's *Ville Spatiale* –both questioning the long accepted Vitruvian notion of *firmitas* and suggesting ideas of choice, freedom, and individualism though flexible soft systems [2].

Sanford Kwinter defines a soft system when he writes:
"The system, one might say, is driven by its very 'softness,' its capacity to move, to differentiate internally, to absorb, transform, and exchange information with its surrounding [...] A system is 'soft' when it is flexible, adaptable, and evolving, when it is complex and maintained by a dense network of active information or feedback loops, or put in a more general way, when a system is able to sustain a certain quotient of sensitive, quasi-random flow." [3]

In other words, a system is soft when it is driven by dynamics, responsive to change, and comfortable with chance and indeterminacy. As with the architectural projects of the 1960's, soft systems were under investigation in many disciplines at this time, including philosophy and the sciences, and represented a common thread of speculation. Importantly, multiple disciplines, which integrate the topic of chance, also deal with the soft systems. Chance has been an area of interest present in day-to-day life, a topic of many works of literature, a technique embedded in mathematics and statistics, and an open concept in the softer sciences. Chance because of its vastness has also been a major idea of interrogation in philosophy, including Aristotle's philosophical work *Physics,* which sought to examine the relationships and systems of nature [4]. While these references provide an overview of an ongoing interest in chance and soft systems relative to both phenomena and techniques, the research in this manuscript seeks to explore the opportunities, which lie in material and machine based approaches for appropriating soft systems in design.

2 Soft Computing in Architecture

Computational techniques in architecture today engage in a multiplicity of approaches, which often involves designers borrowing concepts from computer science and adapting them to specific design problems. Similarly, this manuscript examines a collection of on-going research projects, which borrow ideas from soft computation applied to design and architecture. Soft computing as defined in computer science is "a collection of methodologies and computational approaches which aim to exploit tolerance for imprecision, uncertainty and partial truth" [5]. In other words, soft computing often involves development of approximate or soft solutions to computational hard tasks often applied for the development of intelligent systems. Import subtopics of soft computing, which are applicable to this research include fuzzy logic (FL), which works within a range of values, and evolutionary computing (EC), which works based on trial and error [6]. These subtopics are further explored and applied to the research projects outlined in this manuscript through analogue and machine approaches to computation.

Negroponte's book, *Soft Architecture Machines,* was perhaps the first formal introduction of soft computing in architecture and proposed ideas of self-generating and adaptive architectures. Negroponte offers an alternative to the long-standing ideal of firmness, by exploring softness in design with methods ranging from movement and materials to intelligence and computers. More recently, John Beaumont explored this architectural dichotomy of hard and soft pointing out that even the materiality of architecture embraces firmness when "clay is fired into brick, wood is dried and compressed, and sand is melted and annealed into its solid form" [7]. This research investigates these moments of softness before the translation into hard. More specifically it investigates softness as a tool for innovation in computational design relative to advances in automation and robotics.

The vastness of softness in architecture is further outlined in *Bracket*: *Goes Soft* which articulates that soft "describes material qualities, evokes character traits, defines strategies of persuasion, models of systems thinking and problem-solving, and new approaches to design [2]. Similarly to Kwinter, this issue argues that softness is a way of addressing contemporary complexity in design, which requires room for flux and indeterminacy. Bhatia argues that historically "the role of the Architect has been to determine lines that ordered the world;" however, rapid changes and transformations have "sparked a disciplinary identity crisis characterized by a yearning for architecture's opposite, flexibility, dynamism, immateriality, and indeterminacy" [8].

Therefore, soft in the context of this research takes on a multiplicity of meanings, which relate more to material characteristics, reconfigurability, and as a model for systems thinking. This multiplicity of definition allows each of the subsequent research projects to not only engage in softness as a computational idea, but also investigate their potentials for material based approaches to appropriating technology in design.

3 Softness in Advanced Manufacturing

Returning to the topic of chance, it is important to note, uncertainty or imprecision is often avoided in manufacturing, and construction. Present day research looking at the advancement of manufacturing processes is often centered around material techniques [9]. The projects examined in this manuscript also take material investigation into account; however, they differ by examining soft computing methods relative to materials and machines. Each project pairs a certain degree material unpredictability with the rigid order of machine control. Currently the common categories of tools and manufacturing process include: Subtractive Processes or Material Removal; Molding, Deformation, and Casting; and Fabrication or Additive Processes [9]. The three projects described investigate each of these machine processes by integrating material indeterminacy.

Each project begins with the question, 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 machine control? Drawing upon these questions and the lessons from the histories of instrumental knowledge, indeterminacy, and softness, we find the context for the polemical suggestion for opportunity driven research relative to soft computation in design.

3.1 Additive Material Indeterminacy

This first research project, entitled Motion Capture, examines the potential for integrating soft computation in design by integrating material indeterminacy in an additive manufacturing process by seeking to capture opportune moments of material fluidity. Other additive based systems which integrate softness and precedent this work include Roxy Paine's automated sculpture makers (1996-2001) and Anish Kapoor's 3d printed concrete (2012). The project involves the development of a 3D printer, which uses gravity as the z-axis to freeze key fluid moments in a change of state material (illustrated in Fig.1-3). As seen in his iconic photograph *.30 Bullet Piercing an Apple* by Harold Edgerton, which strives to capture key moments of movement using multi-flash process, the Motion Capture project similarly tries to still moments of formal interest during the curing process. The project tries to find the equilibrium between the cure time and rate of deposition through material testing.

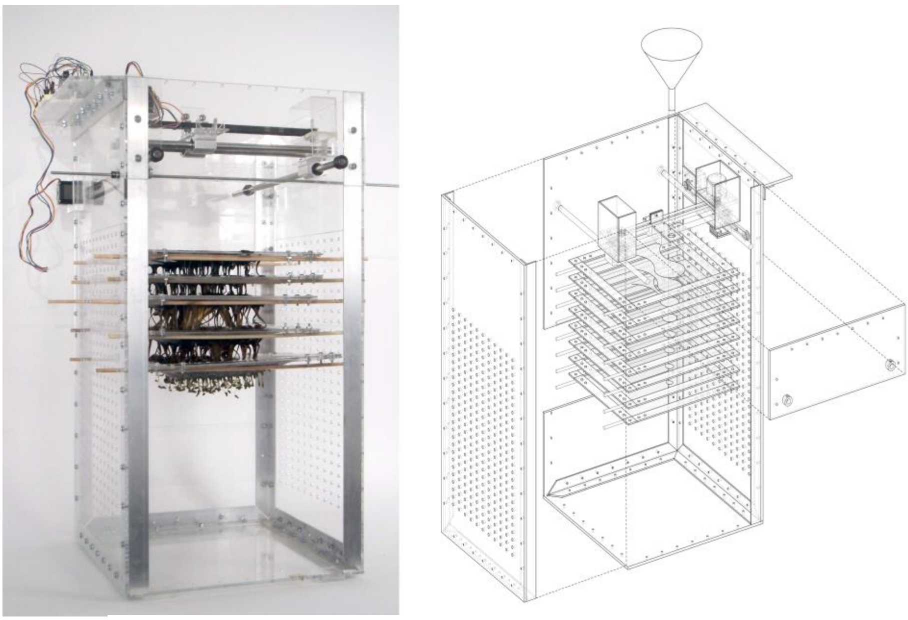

Fig.1. Motion Capture 3D Printer and Axonometric Drawing

The research method involved a two-part process of material testing and automation development. The material tests sought to find a balanced ratio of the ingredients: vinyl acetate copolymers, resin, wax, and sucrose. The evaluation criteria during the testing involved cure-time, toxicity, strength, elasticity, and fluidity appearance after flowing through extrusion armature and changing state from liquid to solid. Figure 4 catalogs the documentation of these tests relative to each of the criteria. Each test sought to arise to a challenge developed by the research team which involved asking, how might we develop a plastic composite with low toxicity levels when heated and which easily decomposes when discarded? Additionally we asked, how might the material stand and support itself once it was cured to capture material fluidity (Fig.5-

7)? How might the extrusion amateur dissolve or melt by building it out of a material such as ice, which would melt from the heated solution during the curing process?

Fig.2. Detail Images of Motion Capture Printer Output Prints

Once the team achieved the ideal material composition, the testing began for the additive automation strategy using a 3D printer built with Arduino, a programmable micro-controller, and controlled with Firefly, a plug-in for Grasshopper. The automation strategy integrated a controlled constant rate of deposition and a variable location in three axes. The variable location of deposition and speed of the printer would produce effects not entirely predictable except within a range of possibilities exemplified by sending identical prints and documenting the range of changes from each one. While this printer is only an initial study of how construction methods might integrate ideas of material indeterminacy, it provides designers with an imagined scenario where they could rethink existing methodologies—perhaps no longer working from intent to execution, but starting with material execution strategies and speculating on the range of possibilities from there.

Fig.3. Motion Capture 3D Printer Output Print

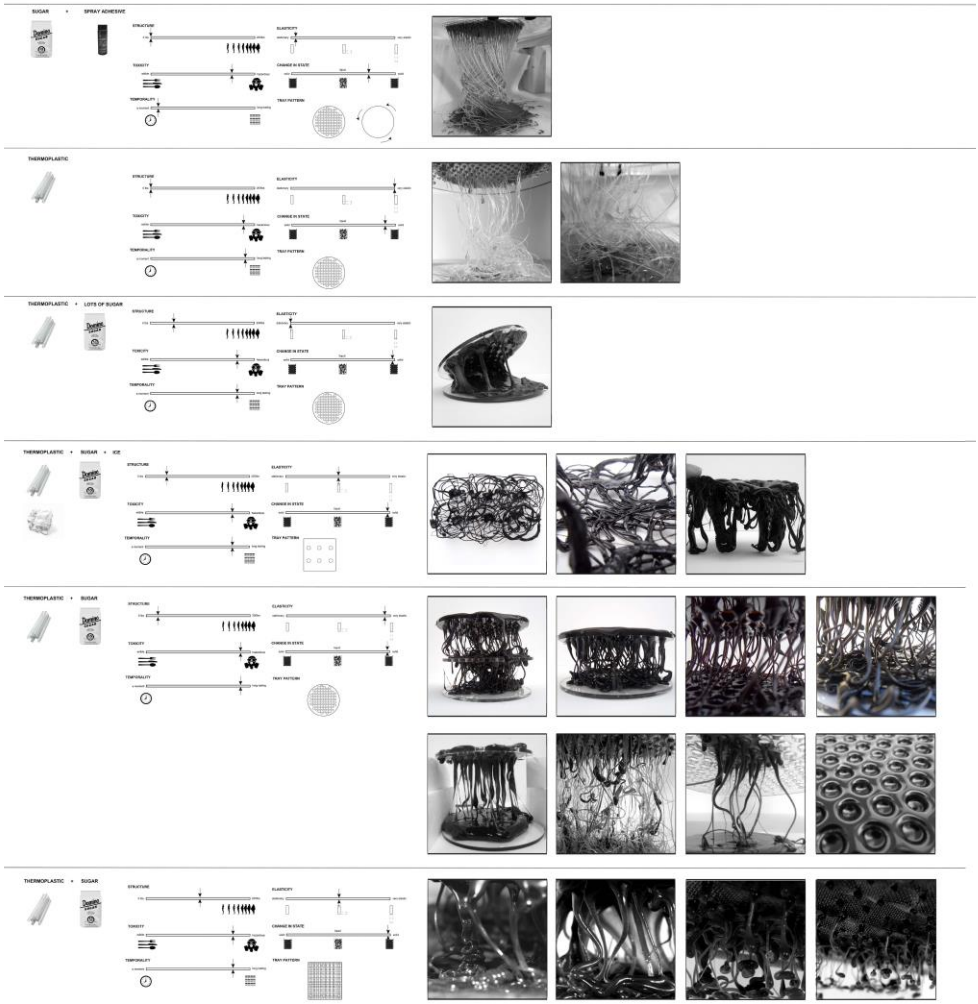

Fig.4. Taxonomy of material tests illustrating cure-time, toxicity, strength, elasticity, and fluidity appearance after changing state from liquid to solid

3.2 Subtractive Material Indeterminacy

The second project, entitled Objects of Rotation, strives to explore a subtractive process, which results in varied material effects by pairing the soft and malleable material, clay, with the automated control of robotic technology. It draws from the craft based process of throwing and interfaces traditional ceramic tools with the robotic arm to develop a subtractive tooling process which carves away while the ceramic wheel is rotating, similarly to how a lathe operates (Fig.5).

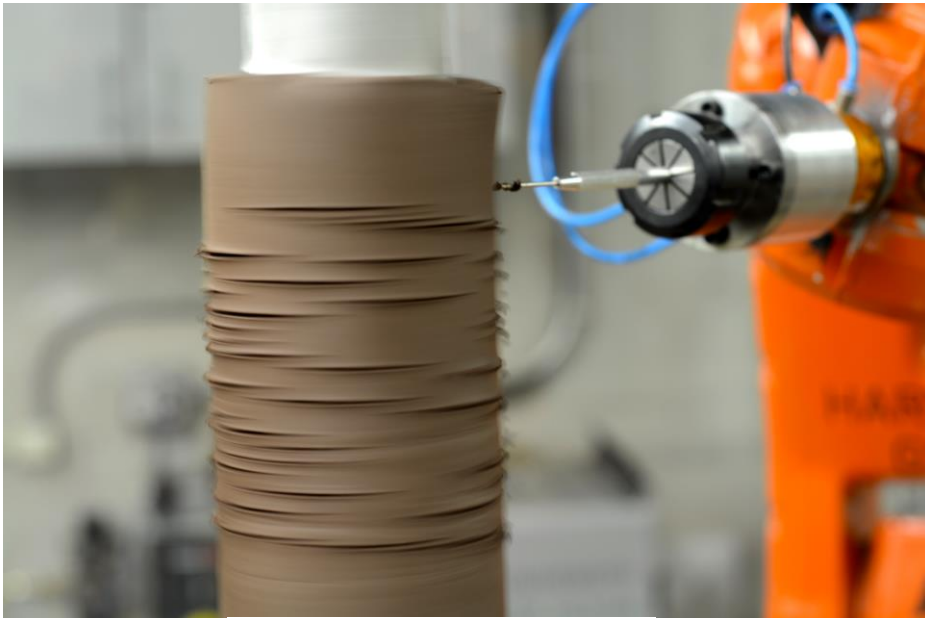

Fig.5. Objects of rotation research setup

The setup involved traditional ceramic carving tools integrated into a collet for robotic control of the toolpath. The tool then moves along an extruded clay cylinder while in rotation. This area of this research was an extension of an earlier project, which sought to explore automated tooling methods related to craft based processes [10]. This development specifically seeks to catalog the range of material variations from a consistent tooling process relative to understanding material indeterminacies. The research team ran each tool path multiple times in order to show the variations in the carving process from identical test runs.

By cataloging the material responses to the carving process certain target results were predictable; however, the exact replicability of each experiment was not possible nor desired; instead, the unique characteristics within the research and tooling development were celebrated. The research team describes materials, which produce these unique effects from an identical process as *materials with fingerprints*, meaning the materials which are embedded with unique identity such that the results, in repeated experiments, are distinct from one another, but recognizable as a *relative* because of similar characteristics.

3.3 Casting Material Indeterminacy

This last project examines the potential of material discrepancies caused during the casting process caused by elasticity of a fabric layer in between a robotically calibrated reconfigurable pin-mold. The overall setup for reconfiguring the pin mold involves the robotic arm with a steel push pin held in place by the spindle, a pin mold (made up of 121 pins, an aluminum plate, and a two inch rubber clutch layer), and a base scaffolding to elevate and position on the mold. Once the mold is set with the robot pushing pins in place, an enclosure box is place around the pins with a spandex lycra fabric layer on top to prepare for casting (Fig.6). While the pins are precisely placed and calibrated, the stretching of the fabric due to its placement and the weight of the plaster cause irregularities within the casts.

A parametric model allows for the development of the tool path for pushing the pins in place to calibrate the mold. The research team also used a physics engine to try and simulate the unique attributes of the casts such as the stretching and wrinkling in the fabric. By calibrating the mold in an identical pattern and producing multiple casts, the research team was able to document a range of possibilities as a result of the variations in stretching for each test (Fig.7).

The research team also decidedly chose this last method, not only to test indeterminacies in casting relative to machine control, but also had an interest in indeterminate conditions relative to human response and interaction since the resulting casts attempt to evoke a haptic response through their visual implications of softness. Overall, this project attempts to demonstrate the capacity of architecture to engage indeterminate processes in fabrication process and through experiential interaction. While this study of interaction is only a surface based approach, there lies a greater opportunity to explore ideas of interaction, which are fundamentally relevant to the soft computing discourse of artificial intelligence, which aim to develop systems capable of responding to change, imprecision, which are all fundamental characteristics to human behavior or response to environments.

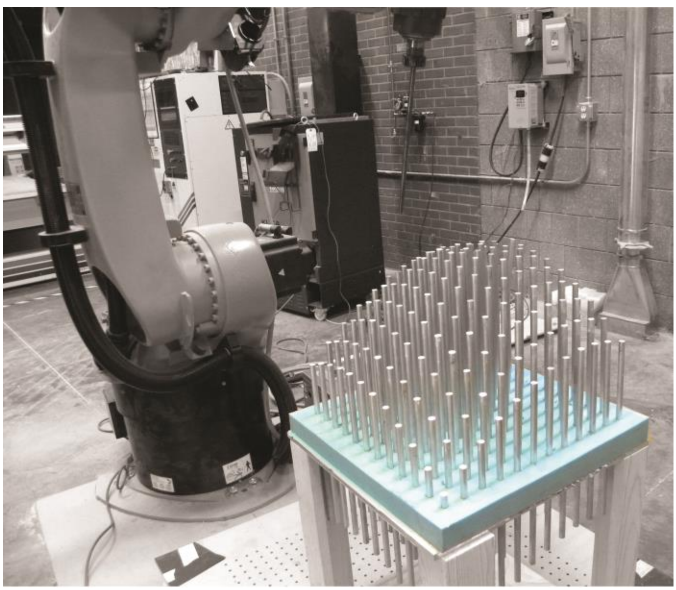

Fig.6. Reconfigurable pin-mold

Fig.7. Resulting casts

4 Conclusion

These experimental projects ultimately aim to address the question, how might we orchestrate a scenario which celebrates material indeterminacy as a design opportunity and integrate material effects into automated strategies for manufacturing and construction? By embracing indeterminate material results, it is import to note that these experiments also provide a framework for further exploring feedback in systems in stochastic processes for soft computing relative to interaction and intelligent systems.

Going back to Negroponte's interest in collaborative machines this study of material indeterminacies provides room for further research with self-influencing systems. For instance, with the scaling up of the Motion Capture device, the question arises regarding how feedback could allow the system to scan and recalibrate in order to provide sufficient structure or delineate and differentiate space. With this type of development, lies potential for integrating machine-learning processes as an additional method for appropriating soft computing techniques within the system.

With developments in large scale 3D printing at University Southern California, the appropriation of robots on construction sites at the University of Stuttgart, and the integration of drone technology in construction at ETH Zurich (*Eidgenössische Technische Hochschule Zürich)*, technological advancements are impacting the way buildings are both designed and built. Integration of feedback loops with 3D scanning and sensors are allowing for additional developments in decision-making machines; fabrication robots will one day be capable of learning from data in real time and make decisions about the next moves.

This continued research takes on two parts. First, it involves illuminating the possibilities of what can be, by looking at history as a way to see the world and as a predictor of what may happen. Second, it attempts to demonstrate the proof those possibilities through research projects, which actualize those ideas. Looking at history, we see ideas of indeterminate construction methods dating back to Ruskinian notions of savageness, a characteristic of the idiosyncrasies, mistakes, and imperfections in the construction of gothic cathedrals made by craftsmen, often due to harsh climates and conditions in which they built. Ruskin saw these rough details as beautiful attributes because they told a story of the workers and were markers of the act of construction [11]. Embracing the Ruskinian notion of savageness, this research leans against the tendency of technology to generate uniform results and embraces the idea that originality arises from imperfections, even material irregularities made by machines. In a future of buildings constructed in collaboration with intelligent robots, what Ruskinian markers or savage details will result? Will the buildings tell of extreme precision and control or will they deviate and embrace material indeterminacies? Will robots be capable of thinking creatively?

Antoine Picon, in his assessment of robots in architecture, points out, “Robotic fabrication may confront us for the first time directly with the need to cooperate with our technological auxiliaries rather than simply use them” [12]. Looking beyond material and tooling methods, Picon draws upon Negroponte’s ideas and opportunistically calls for the emancipation of the robot, no longer acting as a workforce, but as a contributor to discourse of design [12]. Similarly, Greg Lynn calls for alternative ways of thinking about robots in his introduction to the 2016 issue of *Log*, suggesting the ability to go beyond “robotic fabrication of primitive huts” [13]. Perhaps instead of an obsession with efficiency, predictability, and precision, we should start the quest for opportunistic alternatives for robotics in design, by finding ways to integrate responses to change, uncertainty, and imprecision.

This research outlined here focuses on indeterminacy centered around material and machine agency in architecture. Promoting such agency requires less rigidity in authorship, which promotes softness not only in terms materials and movements, but also relative to artificial intelligence, suggesting machines could have agency beyond merely using them to facilitate human agency. Such a softening of authorship requires room for chance and a willingness for collaboration with computer-controlled methods. In *Soft Architecture Machines*, Negroponte suggests such design faculties might allow machines “to develop their own design methods and methodologies perhaps better than our own” [14].

This is a call for continued advancements in these tools in tandem with conceptual approaches for looking forward. How might we collaborate with machines? How might our relationship with technology provide design opportunities? Finding ways to collaborate with machines becomes a pedagogical and scholarly endeavor in defining the types of knowledge necessary for design and the kinds of information essential for the creative process. Therefore, integrating concepts of soft computation into architecture provides a framework for discussing the qualitative, the subjective, and the immeasurable in a world of machines and data. This collection of experimental projects act as a call to consider our future trajectories and for us to find ways to integrate computation in architecture more *softly*.

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