Bring in the Noise

A robotic-aided framework for the indirect shape translation and molding of inexact geometries.

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This paper examines how mediated translations that embrace indeterminacy - from design to fabrication - can enhance material and tactile explorations. It investigates a dialogue between a digital environment that supports the design process, and fabrication processes that combine tools that are both precise (the robot) and indeterminate (casting/forming devices) in their essential functions. We present a research inquiry into this issue by providing a reflective account of a robotics-aided framework for the fabrication of inexact geometries using reconfigurable pin tools (RPT). These tools, with their inherent indeterminacy and variability, were used as a base mold for casting blocks in concrete and plaster. The central thesis of this paper is that a non-linear fabrication process - one imbued with variability rather than deterministically controlled for formulaic production/outcome - becomes a potent generator of novel forms. By focusing on process, rather than on the product of design, designers can subvert the geometrical control inherent in a digital-material output, thus favoring discovery over order and material sensitivity over determinacy - essential qualities in progressive architecture practice.

**Keywords:** Reconfigurable pin tool, Robotics, Indeterminacy, Material exploration

**INTRODUCTION**

The research presented here is motivated by the belief that it is critical for architectural designers and researchers to responsibly develop methodologies and systems for fabricating innovative construction methods that are attuned to, and informed by, material sensibilities. In the current context of technological developments, where digital designs are more easily materialized by digi-mechanical (hands-free) means, an important question to ask is, how to design mediated translations - from design to fabrication - that include, enhance, and continue traditions of material and tactile explorations that have been so essential to the human endeavor that is architecture?

Our research inquiry into this essential question - one that prioritizes a tradition of material sensibilities evolved around a digital design-fabrication framework designed to produce inexact geometries. This
progression explored the use of reconfigurable pin tooling - with its inherent indeterminacy and variability - incorporated into a digital-design and robotics-aided manufacturing framework; a process of making purposefully orchestrated to subvert geometrical control of the material output. This framework proposed an indirect translation between the digital and the physical environment, one that becomes further enriched by a mediation composed of high-precision computational tools and the uncertainties of material processes. In this sense, the pin tools developed through this research serves as a flexible and adaptable means for exploring and enhancing the indirect translation mentioned above.

This study also argues that, by designing a flexible robotic fabrication system which enables an indirect translation from the digital to the physical, the manufacturing process becomes enriched by tactile and material explorations beyond the input-output predictability of standard digital fabrication. In this sense, we welcome indeterminacy as a design-making strategy; one that is informed by material discoveries, accidents, mistakes, and curiosities. In a manner more similar to intuitive hand-crafting, the unpredictability inherent in this fabrication framework can inform and enhance the process of creating digitally crafted building components - designs that might begin as one thing viewed on a monitor but result in something quite new and different in their materialization.

**BACKGROUND**

**Indeterminacy vs. control in digital architecture**

In a recent essay, Carpo (2012) argues that digital designers have embraced indeterminacy in designs as long as it is derived from what the author defines as Digital Darwinism: an emergent system that self-select the best-performing solutions. Carpo questions this approach, by stating “*We might choose to favor the emergence of the strongest form, but the strongest form may not be the form we need*” (Carpo 2012:105). Proceeding with this observation, in this paper, we argue in favor of another type of indeterminacy in digital design and fabrication - one that emerges from the playful mediations between the high-precision, predictability, and repetition of digital means; and the unpredictable, heterogeneous and anisotropic nature of physical materials.

Norell et al. (2014) argue that one way to introduce indeterminacy and material exploration in architectural production is to design fabrication frameworks that knowingly subvert geometric control. If *design* becomes a prescription for a material process, rather than the determination of an exact geometrical description of an output, the authors claim, one is able to introduce *noise* and reintroduce material sensitivity into virtual/digital design processes. This paper will use the definition of noise suggested by Norell et al. (2014) to refer to a distortion from the exact translation from the representation of a model to the materialization of the designs.

The strategy of designing material processes rather than defining the final design has arguably been used by many designers and builders. One example of this can be seen in the work of the *Gabinete de Arquitectura* - a Paraguayan architecture practice lead by Solano Benitez and Gloria Cabral - more specifically, in the brick-less wall designed for the MUVA exhibition (2014). The studio built a wall using concrete and unfired bricks, and four days later, the bricks were washed away leaving only the thick concrete joints (Tomas Franco, 2016). The roughness of the smeared mortar and the aesthetics of the final geometry could not be exactly predicted beforehand: instead, the architecture is resultant from the material process.

A prioritization of the material process - as design, rather than the deterministic design of the outputs is, arguably, less common in digital design and fabrication. This condition might be a default - one inherited from the accuracy associated with digital machinery, such as robotic arms and CNC machines, that execute programs based on coordinate systems with little margin for errors. Currently, there is a growing body of literature that recognizes the ben-
benefits of developing adaptive fabrication frameworks when using highly automated tools such as industrial robots. Projects of robotic fabrication in architecture have lately sought an adaptive fabrication approach to mediate the translation between a desired digital result and the actual material conditions (Schwartz et al., 2014). Researchers have also proposed feedback mechanisms to replace fixed instruction with context-sensible rules (Amtsberg & Raspall, 2015). While these approaches negotiate material uncertainties by creating systems that respond to the environment, the framework presented in this study aims to embrace the uncertainties rather than leveraging them.

A significant analysis and discussion on the subject of material indeterminacies in automation frameworks is presented in the work of Dickey (2017a). The author argues for a soft computation approach in design through making, where combining material uncertainties and digital machinery allows designers to see opportunities on elements of chance, embracing indeterminacy in the fabrication process. The explorations presented by the author challenge the notion of technology as a generator of consistent results, celebrating material indeterminacies instead, as design opportunities. The author argues that this approach could lead to a better integration of material properties in digital automated protocols, and to discovering possibilities presented by innovative materials (Dickey, 2017b).

Similarly, researchers have proposed moving beyond the search for seamless translation between the digital and the physical, favoring exploration over efficiency (Cardoso Llach, Bidgoli, & Darbari, 2017). The argument presented in this case is that the seams and byproducts of the interaction between the digital and the physical environment -the noise- can undoubtedly add material sensitivity to the design process. Recognizing this mediation between the digital model, the fabrication strategies (automated and/or analogue) and the physical conditions will also engage the material outputs in shaping a new digital aesthetic, one that is the result of a dialogue with the material used.

Overall, these studies highlight the desire for the development of digital frameworks that mediate between the precise and deterministic nature of automated fabrication protocols and the material indeterminacies of the physical world, while simultaneously allowing for explorations that are sensible to the form, texture, and relief of form. This paper provides a reflective account of a framework that purposefully introduces noise and chance into the manufacturing process, subverting geometric control by focusing on the manufacturing process rather than the outcome.

Reconfigurable pin tool
This paper documents and discusses a series of explorations using a reconfigurable pin tool (RPT) with its variability and inherent unpredictability, employing an analogue-digital framework. A reconfigurable tool, for manufacturing purposes, can be defined as a machine that can be readjusted to shape materials (Munro & Walczyk, 2007). The pin tool used in this research consists of a reconfigurable bed similar to the 3D pin-art tool patented by Fleming in 1987. Research on reconfigurable pin tooling has received a considerable amount of attention in the search for a flexible tool that allows for repeated/reusable fabrication of unique geometries. The term reconfigurable pin tooling in this study refers to a matrix of pins that can be adjusted in the Z axis to adopt variable shapes and forms. Transformable dry mold (Fereos & Tsiliakos, 2014), flexible actuated mold (Oesterle, Vansteenkiste, & Mirjan, 2012), or variable geometry molds (Pedersen & Lenau, 2010) are other terms used to describe iterations of the same tool.

Reconfigurable pin tooling is used in this research as a fabrication method for casting free-form surfaces using concrete and plaster. This fabrication method presents several benefits over other approaches to mold-making, such as milling, 3d printing, vacuum-forming or hand-work. A significant advantage is that the mold can be changed between castings (Pedersen & Lenau, 2010), without the need
of a fixed or rigid mold. Most importantly, the same tool can be used to cast variable geometry (Bell, Barnes, Ede, & Read, 2014), reducing cost and waste material in construction. Many of the current production forms employed to make complex-shaped or free-form panel geometries rely on the practice of milling formwork from less-than sustainable materials for each unique piece. Therefore, the reuse potential of the reconfigurable tool presents several significant advantages at multiple scales of impact.

It is beyond the scope of this study to create a manufacturing system to produce accurate complex-shaped blocks; other researchers have already been addressing this type of questions. On the contrary, our framework was designed to enhance material explorations through the byproducts of the system. This study utilizes the reconfigurable pin tool as a means for exploring a flexible and indirect system for the materialization of unique shaped blocks, where noise is purposefully introduced. What follows in the next section is a discussion and documentation of the explorations conducted.

**DESIGNING THE FRAMEWORK**

The project started with the design of the experimental framework as shown in Figure 1. The proposed sequence initiates with the design of complex surface, having a visual feedback of the overall targeted geometry. The visual feedback predicts the resulting shape without considering the noise and indeterminacy introduced into the system. After designing the shape, a grasshopper script generates a toolpath for the robot to reconfigure the pin type tool. The toolpath is designed in a way that each pin is depressed until the center of the pin matches the target surface. The program for the robot is generated using a plug-in called Robots (https://github.com/visose/Robots/wiki), which generates the rapid code within the Grasshopper environment. The Grasshopper script also divides a larger surface into smaller blocks and creates the toolpath for each of the block units, as shown in figure 1.

The robot then proceeds to set the pins using a simple tool that pushes the pins to the desired position. The program can be run a second time to check the position of the pins, or to adjust the height of the overall surface configuration implicit in the pins, controlling the width of the blocks. The reconfigurable pin tool is covered then with a box that provides the borders for the mold. The next step within the framework is to place a textile membrane on top of the pins, attached to the box. Several textile types were tested, with different degrees of stretch and texture. The last step in the framework is to manually prepare the mixture and cast concrete or plaster on top of the pins, thus completing the manufacturing process. Noise and indeterminacy was introduced into the framework in several ways: with the variation in density of the pins of the RPT that created more or less accurate geometries; with the use of different types of textiles as a base for casting; with the different pin “caps” tested; and with the combination of analogue
and digital processes in the framework. All these variables mentioned above constructed the three different iterations of the RPT. The distinct iterations where tested exploring how the variables mentioned above affected the tangible result. All the iterations shared the same overall dimensions of 16” x 16”, and the dimensions of the pins each went from 10 to 12” long.

The three variations of the reconfigurable tool are seen in Figure 2. The first iteration was comprised of a 6 x 6 pin matrix, using wooden dowels as the pins. The pins had a diameter of 7/8”, and a length of 12”. The second iteration used the same pin matrix and the same set of dowels but used 3D printed caps with a quadrangular base. The caps served the purpose of softening the resulting geometry of the tool. The last tool had a matrix of 9x9 pins, with a diameter of .6, using PVC piping tubes as pins. All the iterations used rubber O-rings to keep in place each pin. The O-rings were kept in place between two plywood boards. The tools developed were placed on top of a metal structure that kept the pins at an adequate height considering both the movement of the robotic arm and the workability for casting purposes.

RESULTS AND DISCUSSION

The framework successfully combined automated fabrication strategies with analogue methods. While the design of the geometries, the creation of the toolpaths and the robotic reconfiguration of the pins was mostly done in an automated digital manner, the second half of the process was done manually casting the pieces into the mold. The analogue part of the fabrication process also added noise into the system, due to the fact that the preparation of the mixture was never done exactly the same way, creating variations in color and texture among the pieces. The use of the robotic arm, on the other hand, allowed for the easy reconfiguration of the pin tools as per the digital model. A simple 3D printed tool was attached to the end-effector of the robot, as shown
Figure 4
Textures of the resulting casts. (L) cast from 6-pin grid with 3D printed caps, (C) plaster cast from 6-pin grid using 7/8" pins, (R) concrete cast from 6-pin grid using 7/8" pins.

in Figure 3, to push down the pins of the RPT. The resistance created by the O-rings was enough to keep the pins in place while allowing to rearrange the pins with the robotic arm easily.

The resolution of the pins accounts for a significant variation in the overall result of the cast. The RPT tool with a matrix of 9x9 pins (the densest matrix of pins tested) more clearly represents the digital target surface than the other iterations. Figure 3 shows the 9x9 pin tool reconfigured, the matrix implicitly showing the type of targeted surface. The tool iteration of 6x6 pins presented the most unpredictable results from the fabrication process, due to the low resolution and the use of a stretchy elastic membrane/textile on top.

The elastic membrane/textile substantially increases the level of unpredictability in the targeted shape. By changing the type of textile used in the process, one could obtain an entirely different result, even maintaining the other variables of material and pin reconfiguration. The use of the textile as an intermediate material, therefore, conditions and shapes the translation from the digital environment to the physical result.

Overall, the targeted shapes differ substantially with the casted result. The indirect translation between the digital environment and the physical output created by the low resolution of the proposed pin tool softens the initial targeted digital geometries into inexact shapes. The mediation between the digital and the physical output is also a result of the material nature of the elastic membrane/textile used for casting. An unexpected outcome of the manufacturing process was that the pins of the RPT leave a mark on the casted piece, as shown in the figures of the right in figure 4, which gives the pieces a character that could not be predicted in the digital environment. When observing the casted pieces, one questions the ability to ultimately predict the resulting form on the digital environment.

The second iteration used 3D printed caps to erase the pin marks obtained in the first exploration, and to restrict material deflection of the elastic membrane under the weight of the liquid concrete/plaster. The use of caps is adequate for achieving a smoother surface, and overall a more predictable result. An interesting point in the reconfiguration of this second tool is that since the caps are close to each other, the robot may "accidentally" depress the surrounding pins while pushing one pin down. This adds another layer of unpredictability to the fabrication process and can be further explored with the development of a pin type tool in which the movement of one pin affects the movement of the surrounding ones. Figure 4 compares the textures of the resulting blocks. On the left, the casted result of the tool using the quadrangular plastic caps.

The study also explored the possibility of casting two pieces that would be a part of a larger building component, as shown in the proposed digital framework illustrated in Figure 1. The continuity between the two pieces is not as evident as expected,
especially between the casted pieces with the low-resolution pin tool. Nevertheless, the exploration shows the possibility of implicitly constructing larger building components, with the same reconfigurable pin tool. Figure 5 shows two casted blocks intended as part of a larger surface geometry.

CONCLUSION
This designed analogue-digital framework successfully enhanced material exploration, prioritizing material sensibilities over order and determinacy in the fabrication of inexact geometries. By focusing on the design of the fabrication system, rather than the outcome, the proposed workflow left space for the introduction of chance, error, indeterminacy and serendipitous discovery. The variability of the reconfigurable pin tool, the indirect translation of the digital model to the physical, and the combination of manual methods and automated machinery derived in a framework where the resulting geometry had added material sensibility in the form of color, texture, and even shape.

The unpredictability of the material outcome was a result of the "stretchiness" of the fabric, the manual casting process, variations in pin resolution, the use (or not) of pin caps, and the volume of material that went into the block (more concrete/plaster on the RPT = more noise, as it stretched the elastic membrane and deflected pins). These strategies deliberately subverted geometric control of the output by producing systematic errors in the translation of the geometry form digital to physical. All these variables and features of the fabrication process add qualities to the final product that were not present in the digital model. These qualities, such as texture or color, can only be obtained with material manipulation, and cannot (yet) be readily predicted with computational tools. The purposeful introduction of noise and chance into the system also rendered unexpected results: the robot that "makes mistakes" by pushing down more than one pin at the time, adding a random error to the system.

Finally, rather than obtaining precision or high accuracy manufacturing, normally associated with robotic fabrication, the proposed system enables robotic mediations for unique material explorations. The resulting blocks do not portray the typical aesthetics of a digitally fabricated element. In fact, this paper argues for the emergence of a new aesthetic of the digital, as a result of mediated frameworks that favor material discovery over predictability. This aesthetic image of the digital would also reflect a material-machine dialogue, rather than a machine over material condition, typical of purely digital fabrication prototyping machines.

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