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RoboPinch – Robotic Manipulation of Fabric Formwork for the Creation of Plaster Architectural Models

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Abstract

Translation does not always result in a 1:1 exchange but instead, new discoveries can be made through the translation process. Within a discipline such as architecture that historically relies on others to execute designs, translating from digital to physical becomes one more exchange to discover additional insights into a design. In response to this translation-heavy practice, many new technologies are emerging that both capture and communicate instructions for construction. The connection between digital tools and computer-controlled output gives architects the opportunity to speculate on form, material, and the process of making. Industrial robotics offers an opportunity for this speculation with the confidence that decisions can later be translated to larger processes.

As a means to investigate the translative impact of industrial robotics, fabric-formed plaster models became a focus to explore this topic. Architectural plaster models offer a rich territory for exploration as the volume and weight inevitably distort flexible formwork. The phase change from fluid to solid allows for distortions, sags, and wrinkles while freshly cast plaster can still be modified through cutting, carving, and drilling. This project developed a process of creating malleable plaster molds to be precisely and robotically distorted during casting, and post-processed robotically to further modify form and volume.

Keywords: digital design, technology transfer, architectural models, robotic manipulation.

1. Introduction

> "..it made me aware of the meaning of the crane in design, for it is merely the extension of the arm like a hammer. Now I began to think of members 100 tons in weight lifted by bigger cranes. "
>
> Louis Kahn on site at Richards Medical Center

Digital fabrication and CAD/CAM technologies have transformed the manufacturing landscape and have begun to impact larger construction processes. For all the benefits offered by the integration of digital design and computer aided manufacturing, the role of the material has begun to occupy a position of subservience. In many cases the intent of the designer is established early in the design process. The ability to move directly from file to factory means that the materials are processed or modified to achieve this a priori design intent rather than allowing the material to have a voice.

Tim Ingold makes a compelling case for the relationship between material and making in his concept of growth. He uses the growth as a counterpoint to hylomorphism where a designer's intent is imposed on a material. Hylomorphism stems from the Greek hyle 'matter' and morphe 'form'. (Ingold [3]) Growth is an emergent process where a design joins forces with a material. The concept of growth in making highlights the potential advantage of using flexible formwork where the fluid nature of a cast material can be given agency through malleability, gravity, and viscosity.

One great example of Ingold's concept of growth exists within the work of the Spanish architect Antoni Gaudi. Gaudi produced works of architecture from the late 1870's to the early 1900's. He designed iteratively based on a series of principles surrounding the idea that form comes from nature and as a result has spiritual origins. "It seems that Gaudi employed his small-scale model machines not only to design buildings, but also to develop definitions of the truth and perfection of God's beautiful natural forms." (Smith [4]) Gaudi developed his designs almost solely through three-dimensional physical models using materials which would produce organic form such as plaster and chain, things which would not compromise structural integrity but would produce natural form informed through gravity and added weight. (Smith [4]) His hanging chain models were constructed upside-down and were analogue models for how forces might flow through a structure. The physicality and immediacy of his modeling process stands as a prototype for an architecture studio where form can be tested physically in an unmediated process.

In contrast to the immediacy of Gaudi, Robin Evans describes the mediated dilemma of architecture. In "Translations for Drawing to Building and Other Essays", Robin Evans discusses the disconnection between makers and their finished products. Using the painter, sculptor, and architect as examples, Evans highlights the distinctive differences in both the process of making and the resultant product. As preliminary design, a sculptor creates a small scale model and a painter develops their design through sketch. An architect develops similarly through sketch and model. While the end results for a painter and sculptor are painting and sculpture, the architect's final output is not architecture itself, but the representation of proposed architecture through similar mediums. In order to forge a greater connection between the architect and architecture, he proposes that architects only be able to claim ownership of only that which the architect manipulates with his own hands. (Evans [1])

Given the concepts of material immediacy and growth in the mediated context of architectural production, the challenge becomes how to develop a process of making that can be translated and replicated. Rather than digitize materials through a virtual simulation, a broader research question can be considered about how to retain the physicality of materials and yet integrate it within a digital design process. Parametric modeling offers a digital design methodology where the specification of rules (or operations) instead of resultant form allows a designer to consider multiple and iterative solutions to design problems. Furthermore to couple the iterative modifications of parameters in digital design with the precision of industrial robots for output allows a designer to iteratively make in a precise design environment. The ability to translate and scale this process can be imagined as the relationship between using the same file to laser cut a paper model or waterjet cut a larger sheet of steel. The code to run small robots can be used to make models on a designer's desk and that same code might be deployed on larger robots to fabricate building elements. The translation from geometry to material can be tested by a designer in the safety of the studio cost effectively before the information is handed off to a contractor for the production of full-scale architecture. This translation from geometry to material can also be carried out multiple times iteratively which creates a feedback cycle where material and digital form coalesce into a robust, precise, and repeatable process.

2. Motivations

Given recent trends in design that favor complex surfaces and topology, 3D printing has risen to prominence because of its ability to move from a design model to direct 3D output. The problem with this output method is that there is no material influence or opportunities for discovering or advancing the form beyond that of the existing digital model. In an academic design studio setting, 3D printing can impose financial limitations due to volumetric pricing. If 3D printing is used, it is often used as a final model and not as initial or iterative studies and rarely do the models get post-processed and modified.

Design study precedents were investigated that prioritized solid and volume over surfaces as a means to explore foundational design thinking related to solid and void. Rowena Reed Kostellow's assignments in concavity were used as a model. Kostellow was a founding faculty member of Pratt Institute's Industrial Design Department and her work in 2D and 3D design foundation studies aligned well with the motivations for this research. The concavity exercises asked students to work with plaster models and erode volumes into the mass to the extent that the negative space flowed through and around the mass. Successful projects defined the volumes enough that they could be read as positive forms. (Hannah [2])

While the Kostellow assignment asked the student to carve by hand and operate directly on the material, the focus on subtractive volume highlights additional potential for fabric formwork. Rather than begin with a cubic volume and subtract away from it, flexible formwork allows for a material reduction in the casting. Digital fabrication methods operate subtractively by cutting or milling and then removing material. The digital fabrication by-product results in refuse bins full of wasted material. By using flexible formwork to make plaster casts, there is no waste as the subtractive volumes can be formed or approximated by imposing a force on the flexible material. When working with plaster, the material is fluid and malleable to the point that no material is wasted in the moment of creating interior space.

To tie this solid / void intent to a digital design process necessitates a digital output method. Using industrial robots connects the output directly to the actions defined by a designer. Robots further allow for repetitive casting, accurately reproducing actions that resulted in successful casts, and making minor tweaks while working iteratively. Plaster cures quickly but a 10 minute cure time is a long time to hold one's hands perfectly still in a specific location. This 10 minute cure period is easily held accurately for a robot. This robotic accuracy also makes the investigation of design discovery more feasible by connecting to the digital workflow while simultaneously allowing the flexible formwork and plaster to take its own resultant form. The robotic actions or definition of specific trajectories leaves room and opportunity for the material to respond accordingly. As one works through numerous iterations the robotic movements can be refined to downplay or amplify resulting material deformations.

3. RoboPinch

RoboPinch incorporates a standard of making to capitalize on the natural tendencies of casting materials to create form. By understanding the properties of material, one begins to understand the capabilities, constraints, and tendencies of fluid form. Using plaster as the sole medium provides a versatile material that cures quickly, is inexpensive, and is very light in comparison to comparable casting materials. After it cures the resultant cast is soft enough to be post processed with simple tools, allowing the objects to be coated, sanded, milled, cut, and carved to create new forms. This versatility creates the opportunity to both accept forms that the plaster naturally wishes to take as well as to work iteratively in design through a series of manual operations. By incorporating both modes of working, the RoboPinch method offers the option to parametrically work through design iteration while also accommodating the natural distortions of plaster within flexible formwork.

Understanding material properties of formwork are just as significant as the material with which one casts. In this instance, the crucial key to the production of organic form is the use of formwork which cradles the material but does not force a specific form. A range of flexible surfaces were used as the formwork including cotton, spandex, lycra poly blends, and plastic sheeting of various thicknesses. The fabric type and associated stretchiness or surface texture were tested and deployed based on the size of the cast or the robotic interaction. The different formwork materials would have varied effects such as stretching, wrinkling, folding, or remaining smooth. All flexible surfaces were low cost as a means of keeping with the research mission of fostering an inexpensive and iterative mode of working.

Design prior to casting was limited to the fixed points of the fabric formwork and the position of the robots or the movement of the robot. No 3D model existed for the constructed models, only a set of robot instructions. The reproducibility of the robot actions and static jigging meant that one element could be cast and a series could quickly follow in which small modifications could be made to produce additional studies. This way of making reinforced the parametric mentality that envisioned families of forms as opposed to only one idealized output.

Figure 1: Parametric variation through iterative casting

The RoboPinch work is broken down into initial studies and final models that build on the knowledge gained through the initial studies. Initial models test a basic concept of a formwork, form, or robotic action. These studies are quick and iterative. Final models then bring multiple cast parts together on a plaster base as a means of studying architectural ideas about a building massing and its relationship to a landscape or topography.

Figure 2: Quick and low cost methods yield multiple iterative studies as a means of testing intent.

3.1. Pinch

The *Pinch* series of models was formed using nylon stockings. The linear tube form was stretched between two positions on a fixed jig and the amount of stretch / tension would limit the overall diameter. The robot was fitted with a urethane rounded tool. Two robots were programmed to pinch the plaster filled stocking from two sides along a shared axis. When the two rounded tools touched the plaster is displaced creating a void through the cast part and in some cases distorting the uniformity of the nylon shape. Final models explored the aggregation of these parts and casting them against one another as temporary and shared formwork.

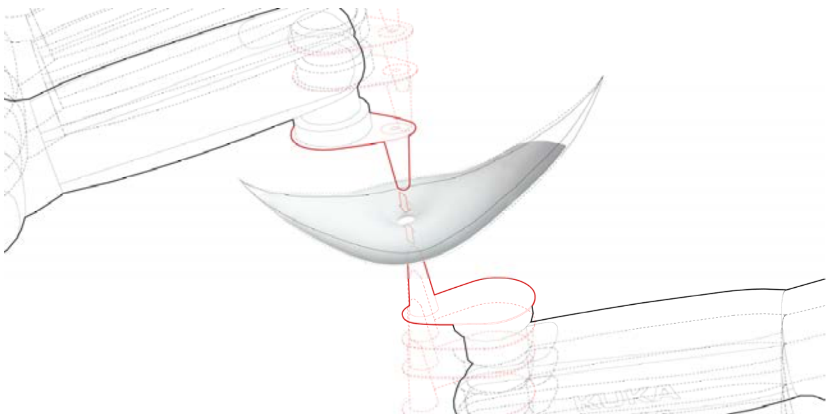

Figure 3: Robotic movement along a shared axis as a means of introducing voids.

Figure 4: Final model using pinched elements aggregated on a plaster landscape.

3.2. Poke

Poke describes a series of casts which exist as small objects cradled in formwork suspended upside-down robotically in order to use gravity as part of the form-finding. A urethane robotic tool pokes into the uncured material, creating a cavity once cured. Turned right-side-up, the form resembles a crater on the textured surface. Aggregation was used to study multiple forms in combination with one another.

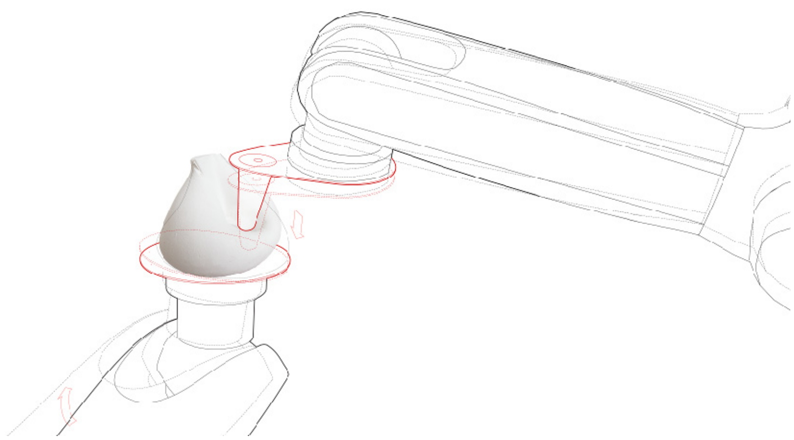

Figure 5: One robot orients a cast taking gravity into account while a second robot introduces a void.

Figure 6: Aggregated poked elements on a plaster landscape.

3.3. Push

The *Push* iteration of models was created using formwork for a rectilinear thick mat of plaster, held vertically in space. Two robots were outfitted with threaded rods that were attached to various points inside the formwork. The rods connected each side of the fabric and creating a void where the pipe pushed through. The robots were then programed to push along an axis perpendicular to the mat, causing distortions and smaller void through the form. These distortions thicken the mat and thin it in other locations, creating soft curves which transition depending on the malleability of the mold. These studies were used as landscapes to form and to become the receptors of subsequent plaster models.

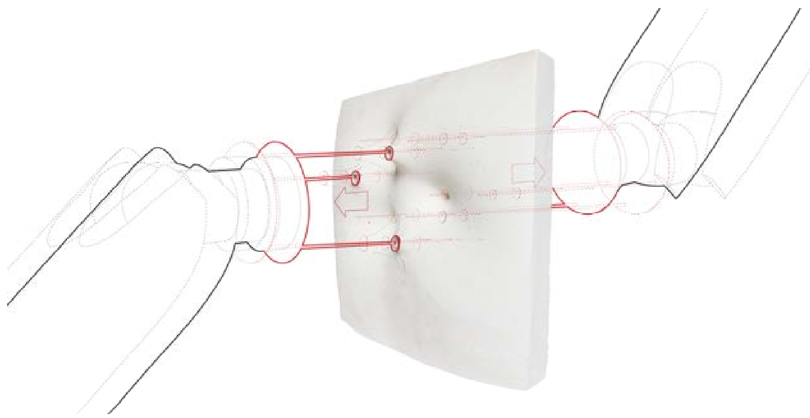

Figure 7: Two robots moving along a shared axis to distort a thick plaster volume.

Figure 8: The pushed plaster volume acts as formwork and receptor for plaster massing volumes.

3.4. Position

Position utilized a method of casting around static preformed objects to create combinations of more complex forms. Various cylindrically shaped 3D printed objects were placed within fabric formwork. The loose objects were then held in position by robotic attachments as plaster is cast around them in space. The interior voids formed by the inserted formwork remain in place and remain empty. The plaster cast around these objects distorted slightly due to the flexible mold at the periphery. The overall form settled into warped moments of concavity hinting at the influence of the inserted hollow objects.

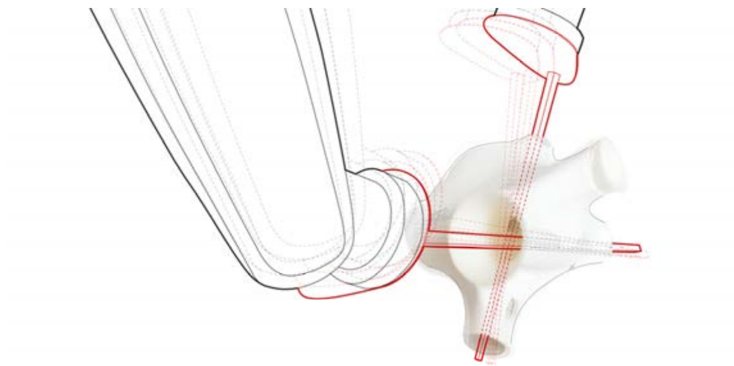

Figure 9: Two robots position and hold 3D printed volumetric formwork within a flexible volume.

Figure 10: Volume of positioned voids act to stabilize the flexible formwork. This final massing volume sits atop a plaster landscape.

3.5. Place

The *Place* series adapts similar methods to those of *Position*, instead casting around previously cast plaster objects. Similar to those found in *Pinch*, the precast objects are of an oblong form with tapered ends. The precast elements were held by the robot and one end penetrated the flexible surface. These models were formed upside-down and plaster was poured from above and gravity determined the shape around the precast object held in place robotically. Once cured and flipped a model is created with protrusions hovering over the landscape.

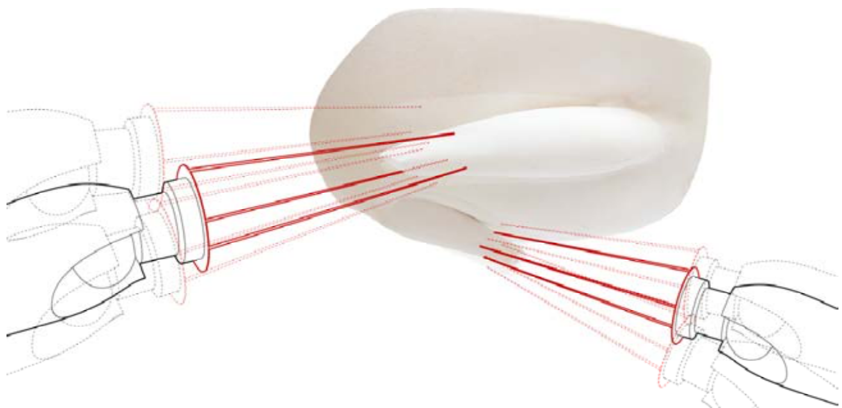

Figure 11: Robots hold pre-cast plaster parts in place to become part of a secondary casting operation.

Figure 12: Final massing model where pre-cast element and landscape become one monolithic part.

4. Future Directions

The recent exhibition of the one year study demonstrates the ability to use this process to develop a broad range of precise architectural models and to do so quickly and inexpensively. These criterion are important from a student perspective as a means of promoting this approach in an academic design studio setting. Given the inexpensive nature of plaster, the models are precise but not precious which means that students are also willing to make post-processing modifications such as cutting and drilling as a way to introduce additional voids or to change the cast form. This process will be added to a Master of Science in Digital Technologies introductory course as a means of furthering the process and investigation of unique tooling.

Figure 13: View of research models on exhibit.

An additional next step in the research is to explore the creation of larger concrete panels that use larger industrial robots to manipulate the surface and introduce voids. This phase will also need to explore new flexible formwork materials that are able to withstand the increased loading as the process is scaled up.

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