Making and Breaking Rules with Algorithmic Forms and Tactile Processes

A Technoceramist’s Adventures with Mathematical Thinking

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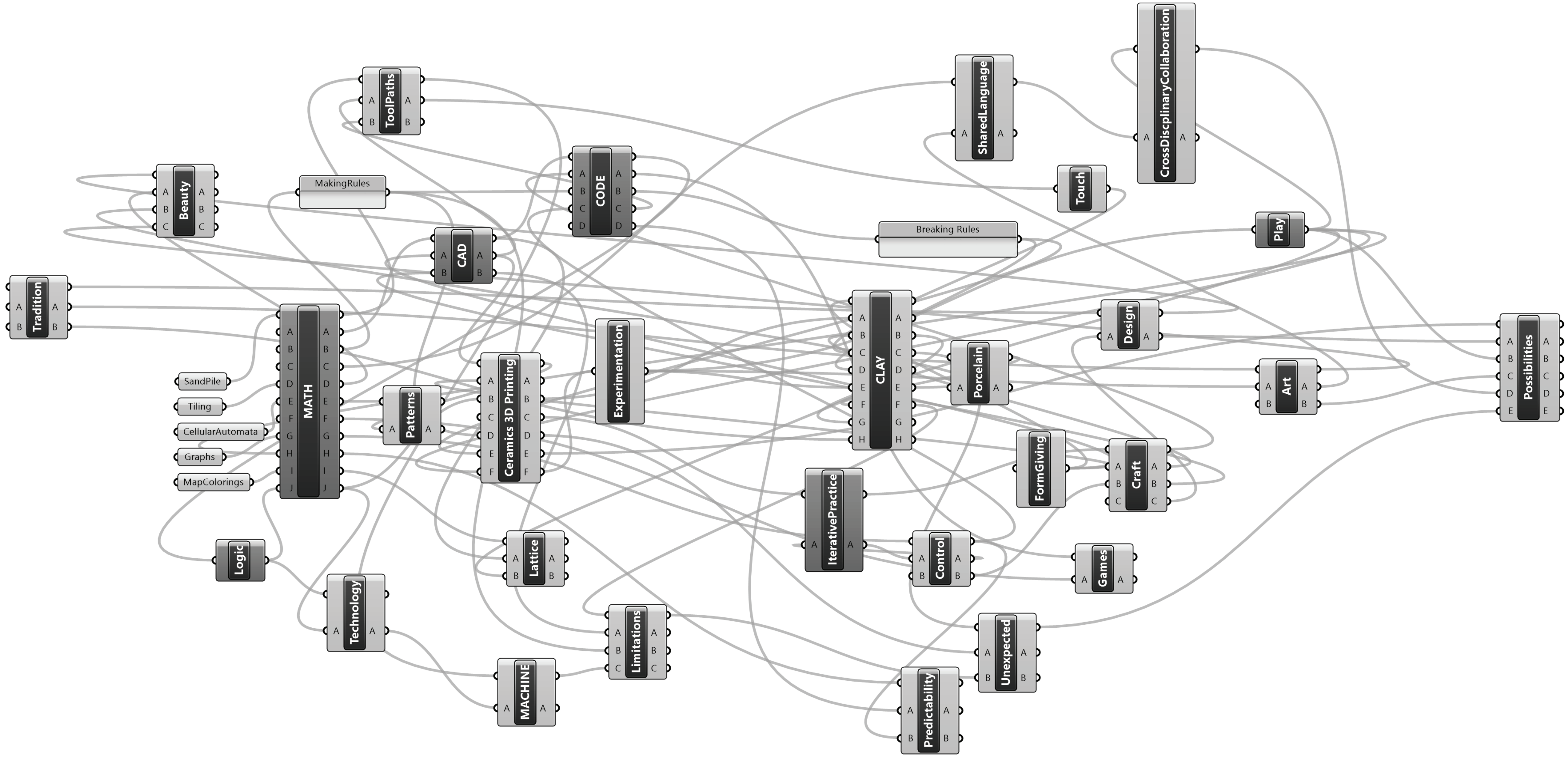
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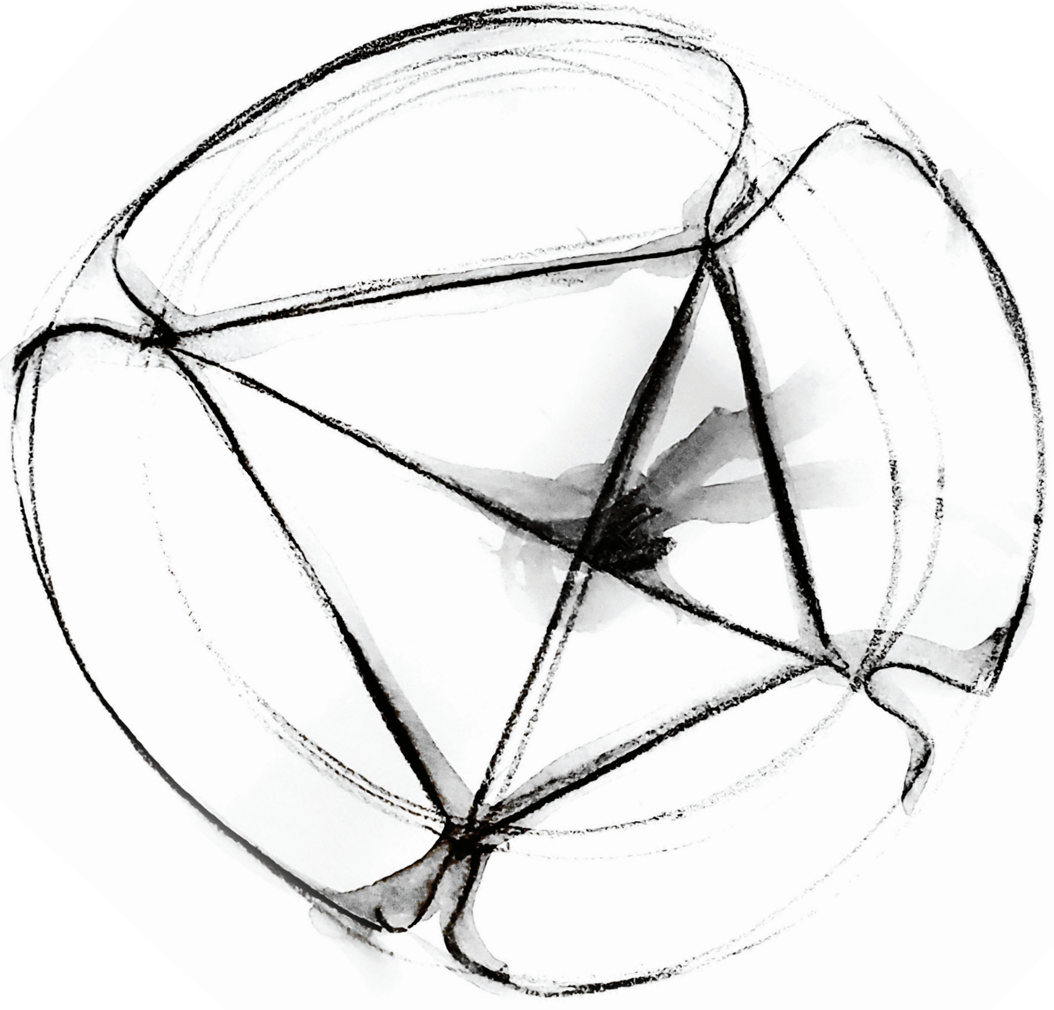

Chapter One

Preparing

What is This Book About?

CREATING A DIALOGUE AROUND CROSS-DISCIPLINARY COLLABORATION Among disciplines, art and math are often posed as a false binary. *Art is free; math is rigidly structured. Art is right hemisphere thinking; math is left hemisphere thinking. Artists are not good at math. There is no room for creativity in math.* Do these sentiments sound familiar? In real life, both artists and mathematicians do their research through a very similar process of strong hunches, false starts, sustained curiosity and hard work. The way mathematicians [01] might refer to the objects of their investigation can sound extremely physical. Words like pulling, stretching, flipping, twisting, dividing, cutting and gluing are as much part of a mathematician's vocabulary as they are part of a sculptor's. Moreover, it is an inevitable part of both the artist's and mathematician's research to arrive at a point where existing tools no longer suffice. Both disciplines find themselves in a position where developing new workflows, methods, software, machines and various other tools [02] go hand-in-hand with the development of actual results. Doing creative work is a self-galvanizing process and one that also requires looking broadly, sometimes outside of the confines of one's discipline.

I'm a visual artist working with clay, math and technology. When I enter my studio, I know and trust that every instance of engaging with ideas, materials and tools will put forward new questions demanding to be considered. *Work comes out of work.* [03] Work only comes of work!

I teach in the Interdisciplinary Visual Arts program at the University of Washington and also run a research and mentoring studio in digital ceramics, Slip Rabbit. [04] As my artistic research, I generate experimental processes for 3D printed forms using clay. During the 2018-2019 academic year, I started a collaboration with Professor Sara Billey of the UW Department of Mathematics. Our joint investigation focused on specific kinds of patterns in mathematics. Our collaboration, which received the Bergstrom Art-Science Award in 2018, also engaged both undergraduate and graduate students through the Washington Experimental Mathematics Lab [05] and through Slip Rabbit Studio.

At the beginning of our collaboration, Sara and I discussed a possible publication for use in STEAM education and by art, math and 3D printing enthusiasts in the general public. In this past year, in addition to public lectures I have given jointly with Sara on our collaboration, I was also invited to give several presentations to diverse audiences from math conferences to art museums. Surprisingly, the most interesting questions I received at these events were not about the printing process or the math but about how cross-disciplinary ideas have kept me moving forward and what role, if any, technology can play in craft. Organizing my ideas for these talks eventually sealed my desire to put some of this content into written format.

Thus, this publication covers a lot of ground from a personal perspective on art and science to reflections on the process of cross-disciplinary collaboration. It introduces the logic of a certain class of mathematical games as well as fundamental 3D printing principles, clay printing and basic clay process. Writing also gave me an opportunity to contemplate the value of the unexpected within a system built to be infallibly predictable. Play and error, material- and code-based processes, the importance of being surprised and of failure also became an important part of this book, as they are an important part of my process to reflect on.

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[01] Especially someone working in areas of geometry and topology.

[02] Throughout the book, I often use the word "tools" in a very expanded sense to mean all the know-how and infrastructure necessary for the creative act.

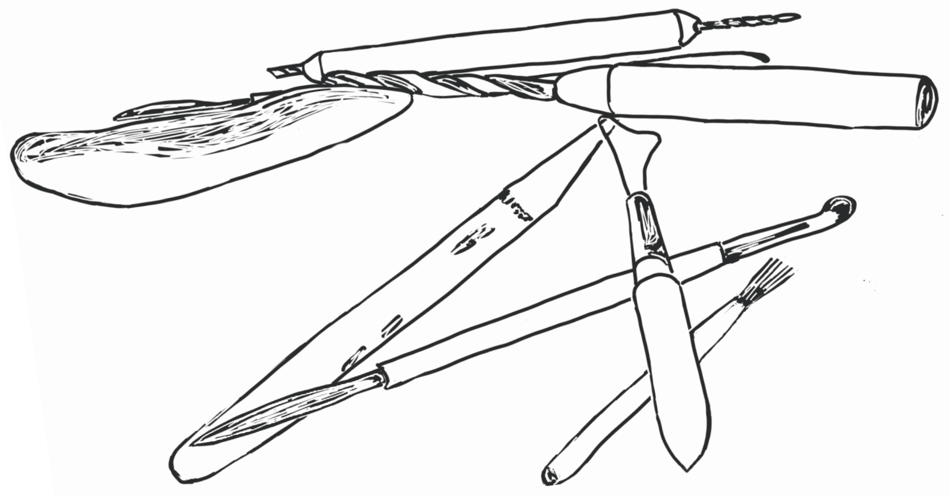
[03] This quote is attributed to the sculptor Richard Serra, whose magnificent steel forms, invoking the beauty of geometry and topology, are created through relentless experimentation in refining both space and form.

[04] www.sliprabbit.org/

[05] Washington Experimental Mathematics Lab (WXML) is research initiative introduced by Associate Professor Jayadev Athrea at the University of Washington, which involves undergraduates, graduate students and faculty in mathematical research. wxml.math.washington.edu/

I will not, though, be providing proofs with relevance to current mathematical research, computer codes, or step-by-step 3D printing or clay handling instructions. For these, a persistent search will easily find various up-to-date tested and true solutions at online software forums, databases and tutorials. Technology changes extremely rapidly. Programs, platforms and commands used today may be completely obsolete by tomorrow. Tempting as it was to hand the reader ready-made solutions, this book was born out of a desire to share a broader picture of a personal journey with art, math, algorithmic processes and a rather unruly material.

My work does not happen in isolation. Stretching my comfort zone to reach out to other disciplines and working through questions by simple but readily available means unearths thousands of possibilities for creative adventures like this one to continue.



A LITTLE PERSONAL BACKGROUND I'm often described as an inter- or cross-disciplinary artist. [06] The interaction of various research fields is crucial to my own practice. Working in this fluid territory, in between areas of knowledge, creates both the content and the context of my work. I've been working with clay for over 25 years, having received both my undergraduate and graduate degrees in ceramics. Even though my main material has been clay (more specifically, porcelain and bone china) [07] in this past decade, I have also worked with various sculptural materials from fibers to plastics, and with video, installation and participatory practices. [08]

In 2016, I founded Slip Rabbit, a research and mentoring studio focused on digital ceramics, which opened its doors to interns, research collaborators and artist residents the following spring. Slip Rabbit is an independent, fully equipped makerspace studio for 3D printed ceramics research, design and education in Seattle. [09]

Considering the INTELLIGENT process within ceramics is important to me. The word intelligent here refers not only to the logical mind or use of smart technology but also to that of the material and the maker's hand. [10] For me, art making is a way of thinking: through my tools and processes, through my hands, through the material and through reflecting on my own thinking. My medium comes with a responsibility toward ceramic history and discourse. Through my pursuits in mathematically-driven and digitally aided ceramics, I aim to reinterpret the ceramic tradition of the vessel—a hollow container built by circling a void—in technical, formal and conceptual aspects and reaffirm this tradition in an expanded physical realm of human experience.

INTRODUCING THE TEAM Much of the mathematical research about sandpile models [11] has grown out of hard work by a Washington Experimental Mathematics Lab research group of math undergraduate and graduate students: Connor Ahlbach, Catherine Babecki, Eli Johnson and James Pedersen. Our monthly get-togethers inspired many ideas for possible math and art directions, which we followed enthusiastically. Eli Johnson, one of our graduate research assistants, eventually wrote his Master's thesis on sandpile models using a hexagonal grid, which gives a highly digestible yet elegantly formalized introduction to the topic. [12] Slip Rabbit interns Daria Micovic, Erica Lee, Annabelle Wu and Wanna Huang were also an important part of the development of the projects presented in this book, as were students from various other majors who took part of the studio's internship program during 2018-19: Kayla Lee, Pooja Krishnan, Caroline Slick, Zeray Admasu, Alison Gray, Nicholas Wong, Xun Cao and Veloria Zhu.

At Slip Rabbit, interns learn the entire process from the math to digital design and ceramic production. Within this workflow, students also have the possibility of finding their own niche, be that in coding, CAD design, clay or even through running our social media accounts. Slip Rabbit's mission is to bring various disciplines together through the emerging world of technoceramics. Our well-attended semiannual open studios are a testament that, in addition to the researchers, the public is curious and excited about this new work.

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[06] I have always had difficulty giving a simple job description for what I do. I prefer to operate outside of clearly labeled categories.

[07] More about these in Chapter 4: FORM GIVING – The Ceramic Process

[08] Participatory or relational practices involve the public into the creative act. They borrow from the playbook of everyday life and often take place outside of the confines of the studio. Many aspects of my own art practice involve creating contexts and offering platforms for others, both to make and to think about the process of making.

[09] At the time of its opening, Slip Rabbit was the very first studio of its kind in the US and, perhaps, in the entire world. During the years since, the studio has welcomed both specialists and the general public. Slip Rabbit has been forging collaborative relationships with makers of all kinds: designers, architects, artists, ceramists and tinkerers. Through internship programs, collaborative partnerships and workshops, the studio is training a new generation of designers, artists, technocrafters and ceramists.

[10] My training in medicine and neuroscience also focused on this relationship between cognitive process and the sensory/physical body.

[11] Sandpile models are a particular kind of mathematical game-like processes, which are described in CHAPTER 4: FORM GIVING – More on the Mathematical Concepts

[12] Johnson, Eli, and Billey, Sara. The Sandpile Group on a Hexagonal Grid. Seattle]: University of Washington, 2019. Available from Dissertations & Theses @ University of Washington WCLP; ProQuest Dissertations & Theses Global. (2311052280).

What is this book for?

In this book, I try to tell a somewhat meandering story about math and art, craft, technology and making. While it is my story, it also has plenty of useful information about math, clay and 3D printing. You can read through the whole book and then return to specific chapters to get a more in-depth understanding of each area or look up the referenced books and online information repositories as you need them. In any case, I want you to know that getting started is easier than it may initially seem. Instead of turn-by-turn directions to follow, my goal is to show you the lay of the land, so that you can create your own path to the most interesting places.

If you picked up this book to learn about getting started with 3D printing or ceramic printing, YOU ARE AWESOME! I too started with only a minuscule amount of familiarity with how to design forms on the computer and took a huge leap of faith. [13] For a novice designer, I suggest starting with one of the many user-friendly 3D modeling programs that are available for free. [14] You can download them easily with a few mouse clicks and test them out. They each tend to follow the same visual-spatial conventions but range from playful to a highly technical interface. In my experience, once you learn to move around in one, the others will seem pretty intuitive. Working with design geometries is not so different from building with little blocks, like LEGOs. I urge you to play! For example, the simplest way to create 3D forms is by extruding 2D shapes or combining simple solids together. [15] Put each design version on a 3D printer and see what works and what needs further tinkering. Keep making changes to the form and to your printer settings and keep notes on what you altered. Don't strive for perfection every single time! Instead, be curious. Start asking what happens if you deliberately push the limits too far. Try messing up, for the sake of art.

If you are familiar with a math program such as MathLab, CoCalc, Mathematica, Processing or if you can write code, try generating a few objects using the rule-based game ideas described in CHAPTER 4. There are also many online repositories [16] of files, which mathematicians and designers frequently contribute to. These offer a variety of mathematical and practical projects to print. You could simply borrow a model from one of these repositories and go ahead: put it on the 3D printer you have access to, and observe it as it builds. As you watch the individual topographical layers slowly growing into a volumetric form, you will learn something new.

I will describe the workflow and the steps involved in 3D printing. If you yet don't have a 3D printer, don't get discouraged. Check with your school, neighborhood library or look up the nearest local makerspace. 3D printers are getting as ubiquitous, affordable and as easy to handle as document printers. There are also various online print services, which will turn your files into objects for which you can select from a range of materials—from a variety of plastics to several types of metal alloys. [17]

I will also explain the basic principles involved in working with clay and ceramic 3D printing. Getting your hands on a ceramic printer or another type of paste extrusion printer may require you to do a bit of research, but there is no reason why you would not be able to gain access to one in your area. Try inquiring at the ceramic department of your high school or university. [18] You may even be adventurous enough to build one, which you can do rather inexpensively with a little guidance. [19] There are also affordable culinary printers using chocolate or sugar icing that work exactly like clay printers at Slip Rabbit do. These machines may not be friendly to nonnative files [20] but are guaranteed to give you sweet and fun results.

Most importantly, I am writing with a simple goal: to encourage the reader to find someone with an expertise in a different area, talk often and look for interesting questions together. The main theme of this book is learning: Learning each other's technical language, learning to ask WHAT IF questions together and learning to follow up on them, even if the anticipated results seem too simple, too futile or plain silly. Mistakes, glitches and detours can add to the joy of this kind of exploration and to the shared discovery—but more about these later. You will get a lot out of being a wide-eyed and meandering wanderer. I guarantee that.

[13] The process was and still is invitingly novel and deeply meaningful, having lots exciting of potential.

[14] The most used of these are:
Tinkercad by Autodesk www.tinkercad.com/
SketchUp Free www.sketchup.com/
MatterControl by MatterHackers www.matterhackers.com/
Meshmixer by Autodesk www.meshmixer.com/
Fusion 360 by Autodesk www.autodesk.com/
Blender by Blender Foundation www.blender.org/
Blocks by Google, for VR arvr.google.com/blocks/

[15] You can do a lot with these basic commands: "copy," "paste," "array" and "boolean". "Array" is a patterning command; "Boolean" combines shapes into one by addition or subtraction. "Extrusion" gives thickness to a flat component or to a drawing. (These specific commands are in Rhino but all other CAD programs have equivalents.)

Who is this book for?

I originally set out to write a practical handbook, but over the course of this past year, it has become evident that while certain truths in math will forever remain unchanged, technology is moving forward with dizzying velocity. This is both a blessing and a curse for a technoceramist. I've learned over the past years that today's discovery could be rendered completely obsolete tomorrow by a newly released device, app or plug-in or by the developer discontinuing maintenance support on a piece hardware or software. 3D printing will soon be as common a technology as digital photo printing is today. My students have an incredible ability to navigate any kind of digital interface. On the other hand, they need more opportunities for manipulating real materials and digitally modeling spatial objects, both of which are significant parts of ceramic printing.

I'm often invited to consult on design or architecture projects that involve printing with clay. Understanding how clay works is an interesting challenge for a designer used to less temperamental materials and processes. Since ceramic extrusion printers tend to lead to less predictable results than other common types of filament [21] printers, printing with clay also gives teachers a playful pedagogic opportunity to foster learning by doing and to emphasize valuable connections between rigorous scientific method, artistic instinct and trial-and-error.

3D modeling software also has the potential to become a teaching tool for practicing concepts in geometry from preschool to college, even complex ones. On the other hand, to be an effective user of the most powerful professional digital modeling programs [22] requires a solid grounding in math. Through ceramic 3D printing, the potential intersections between math, programming, engineering, architecture, design and ceramics seem inexhaustible. In 2019, Sara and I co-delivered lectures to hundreds of students during the Annual Math Day at the University of Washington and to general audiences ranging from preschoolers to software developers at the Spring Math Hour, a public event organized by the Mathematics department. At both of these times we aimed to appeal to both mathematical and artistic sensibilities.

I have presented many of the ideas discussed in this book at various ceramics and math conferences. [23] My own experience with digital 3D technologies in the art context became the foundation for two new courses for the Interdisciplinary Visual Arts program at the University of Washington. These courses focus on understanding digital making practices within the history of art and craft traditions. An examination of larger cultural questions around technology and making, such as how technologically-aided processes fit into the continuum of artistic traditions or how the use of them addresses our everyday experience of the world, is a big impetus for my continuing engagement with research in digital ceramics.

A number of years ago, I picked up a book by Daina Taimina entitled Crocheting Adventures with Hyperbolic Planes. [24] In it, Taimiņa, who herself is a mathematician, introduces hyperbolic geometry through crochet, in an admirably accessible and uncomplicated way. Throughout, she speaks vividly of her craft and about her process of making, which brings an embodied understanding to abstract ideas. [25] I was much inspired by her book, as I was by later books by Henry Segerman [26] and Dries Verbruggen. [27]

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16 Here are some well-known repositories. (Don't forget to credit the source if you borrow and use a file.)
Thingiverse www.thingiverse.com/
TurboSquid www.turbosquid.com/
GrabCAD grabcad.com/

17 Some online print services offer ceramic printing with a resinous compound, which involves a printing process quite different from the one I use. This service is not cheap and it will not give you results similar to those described in this book. The reason for this is explained in CHAPTER 4.

18 Just like Slip Rabbit does, several schools and art/craft institutions offer ceramic printing workshops in the summer or throughout the year.

19 Make your own 3D Delta printer by Jonathan Keep
www.keep-art.co.uk/Self_build.html

20 Printers like these come with a proprietary software package with a lot of premade designs. Designs may use a file type that is understandable only to the particular machine.

21 Plastics, such as PLA and ABS.

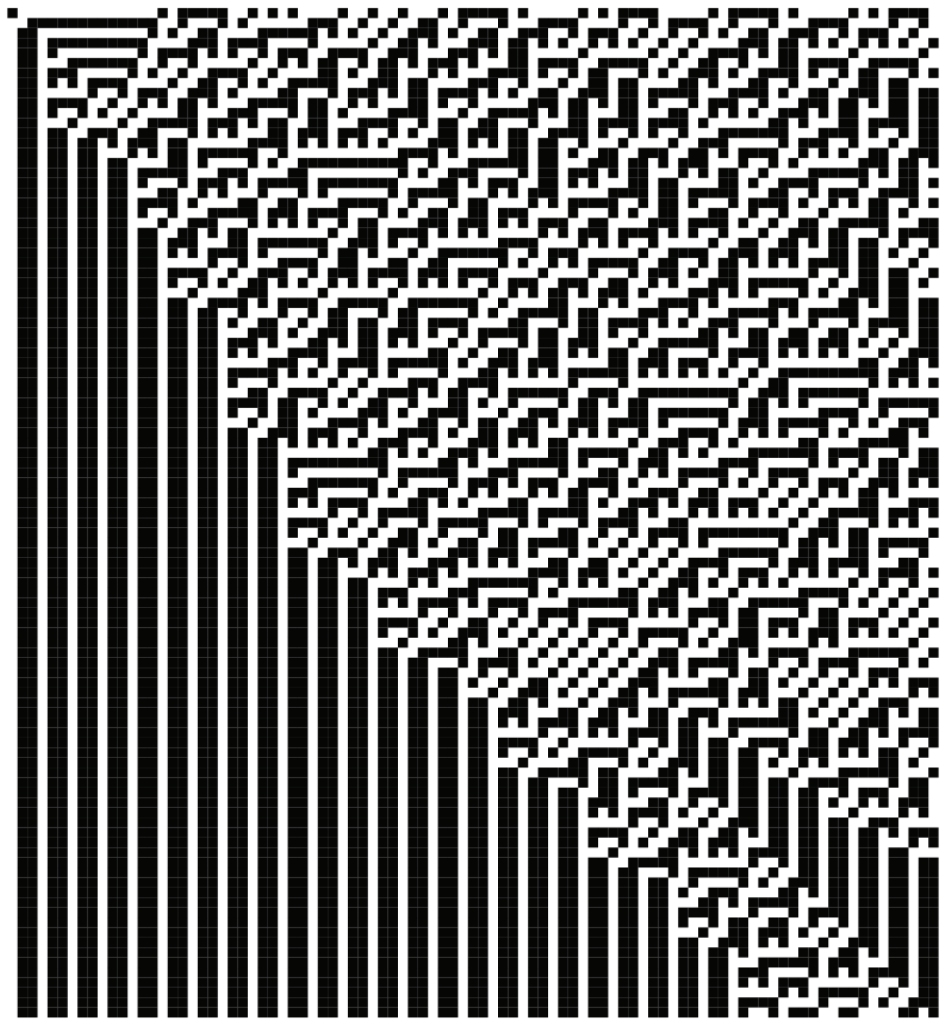
22 The following professional digital 3D design and modeling programs are available by paid license only:
AutoCAD by Autodesk
www.autodesk.com/solutions/cad-software
Solidworks by Dassault Systèmes
www.solidworks.com/
Rhinoceros by Robert McNeel and Associates
www.rhino3d.com/
Grasshopper is a parametric design tool within Rhinoceros. This visual programming environment is developed byDavid Rutten at Robert McNeel & Associates. Grasshopper allows embedded Python scripting.
www.grasshopper3d.com/

23 Recordings of these are online at 2019 National Council on Education for the Ceramic Arts (NCECA) conference, Illustrating Mathematics special semester at Institute for Computational and Experimental Research in Mathematics (ICERM), and the 58th Northwest Mathematics conference.

24 Taimiņa, Daina. *Crocheting Adventures with Hyperbolic Planes.* Wellesley, MA: A.K. Peters, 2009.

25 Hyperbolic geometry does not follow the parallel postulate of Euclidian geometry. A hyperbolic plane can be imagined as a surface similar to a saddle or a Pringles potato chip.

26 Segerman, Henry. *Visualizing Mathematics with 3D Printing.* Baltimore: Johns Hopkins University Press, 2016.



All in all, this publication is meant to be an artist's journal with a goal of demystifying the process of art and the process of mathematics by establishing unique connections between abstract ideas and tangible physical objects that draw from both. Talking with so many people about what I do, how and why I do it, I came to believe that focusing this writing on my own thinking about and making mathematically inspired art projects is not without value for others. I hope to further inspire students of all ages and all backgrounds to engage in creative thinking and problem solving through the elegance of math and the messiness of art making.

Finally, for ceramic 3D printing to be a legitimate area of ceramics, it needs not only more makers but also more writing about its tools, aesthetics and connections to the material. This can only be done by each of us, globally connected community of technoceramist makers: potters, designers, engineers and programmers as well as by theorists, curators, art historians and art critics, each adding our voices and experiences to the conversation.

27 Warnier, Claire, Verbruggen, Dries, Ehmann, Sven, and Klanten, Robert. *Printing Things: Visions and Essentials for 3D Printing.* Berlin: Gestalten, 2014.