Emerging Objects: A 3D Printing Cookbook for Architecture

By Ronald Rael and Virginia San Fratello

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Back to Mud

Mud, or more specifically, a few dozen powerpoint slides of intriguing vernacular mud constructions. That’s all that was needed for me to understand that the work of architectural practice Emerging Objects was more deeply connected with our own discourse at design studio Unfold than I had previously realized. While I was intimately familiar with the research of Ronald Rael and Virginia San Fratello into 3d printing architectural components with sustainable and locally sourced materials, I had somehow missed their shared long time fascination for earthen architecture. That was until I sat down in the pluche at the California College of the Arts auditorium in 2015 during the Data Clay Symposium where both Ronald and I gave a presentation about our respective practices.

In recent years we’ve witnessed an unparalleled explosion of creative expression and experimentation with 3D printing. Not only as a practical tool, but increasingly more as a medium in it’s very own right. A lot of media attention has gone to the wild and often baroque geometric form languages that have been unlocked by the underpinning characteristics of 3D printing. Hod Lipson described in his book Fabricated: The New World of 3D Printing the 10 principles that are fundamental to 3D Printing, the first principle is “manufacturing complexity is free.” Unlike traditional manufacturing processes, where extra complexity requires more expensive tooling, there is no such penalty with 3D printing. And hence we witness a flood of algorithmic designs straight from the future that exploit this freedom as if the objects are unbound by the laws of physics, the limits of real world materials, or the age-old traditions and heritage of making things.

But what Ron presented on stage was not a story about elaborate computational design but a love story for the mundane material that mud is, how it is engrained in the tradition of building worldwide, how ‘one half of the population lives, works or worships in buildings constructed of earth.’ The story of architecture for thousands of years has been the story of mud. This is true for major parts of the world, and where clay or earth was not easily sourced, similar narratives can be told where wood, rocks or ice plays the lead character. And it was at

that point that I understood that this love for the historic and contemporary use of earth in architecture, is the root for Emerging Objects quest in finding a role for new technologies with respect for the codes of how we’ve been constructing our dwellings for ages. With locally sourced, renewable materials that carry intrinsic architectural qualities for which mankind has respected them all this time: humidity regulation, structural stability, natural cooling and so on.

Only had a handful of slides in that presentation were devoted specifically to 3d printing, but for me they brought the story full circle and the project shown - the Cool Brick masonry system - is probably my favourite amongst the projects you will find in this book. The Cool Brick provides passive evaporative cooling in a way similar to how buildings were cooled in ancient Oman before the advent of refrigeration with a system called the Muscatese window, a combination of a porous ceramic jar sheltered from the sun by a wood Mashrabiya latticework. The design of the Cool Brick combines both elements in a brick size ceramic lattice that absorbs moisture and cools air when it flows through its open structure. In a clever way, the cool brick exploits the benefits of Lipson’s first principle “complexity is free” while handily cycling around the pitfall of craftsmanship mimicking over-ornamentation so often associated with 3D-Printing. In a final act, the individual bricks have been assembled in an unapologetic way by setting them in mortar alluding at the act of bricklaying as possibly one of the oldest ‘additive manufacturing’ methods.

The work of Emerging Objects has since their inception been mostly focused on Binder Jetting 3D-printing processes that fuse a powdered dry material. They have been internationally recognised for pushing the limits of this technique by introducing new materials in a normally closed source machine. Since a 3D object printed with Binder Jetting is always supported by the powder in which it is constructed, this process offers some of the highest freedom of form levels of all 3D-printing techniques. As such it seems like an regression that Virginia and Ronald recently started venturing into extrusion based wet clay printing, a process with much higher limitations in regards to obtainable form freedom that we developed in 2009 out of an interest in bridging digital manufacturing with an age old forming technique called coiling. But judging by the impressive and rapidly developing body of work gathered under the moniker GCODE.Clay it certainly feels like using wet clay and its intrinsic limitations and quirky behaviour might be some sort of a home coming. A return to the mud.

Dries Verbruggen

With his partner Claire Warnier, Dries Verbruggen leads Antwerp based design studio Unfold. Together they authored the book Printing Things, Visions & Essentials for 3D-Printing.

Introduction

Emerging Objects & Unnatural Materials

All Building Materials Start As Powder Or End As Dust

At some point in their history, all building materials exist as particulate matter—dust, powder, or grains. Iron ore is crushed and ground into fine particles before it can be transformed into steel. The subtractive process of cutting and sanding wood ultimately reduces trees to sawdust. Grains of sand are melted to form crystal clear glass. The provenance of particles, where they come from, and how material migrations ultimately lead us on a journey that is first geology or biology, becomes architecture via design, and in the end, will emerge as archeology or anthropology, as the specialists of those professions filter through the dust to uncover the fascinating history of material culture that unfolds in it a materials journey from mines, deserts, evaporation ponds, agricultural fields, forests, or factories. [Figure 1]

Building from the “ground-up”, and understanding its history, is central to our philosophy of conceiving of, and making, larger objects. The accretion of small particles, or the assembly of small building components, to create larger components is not a new idea. While mankind has performed the task of adding water to dust to make clay, shaped clay into a brick, bricks into buildings, and buildings into cities for more than 10,000 years, 3D printing has disrupted the idea of handcraft and introduced a deviation to the material lineage of transforming the small into the large.

Our interest in 3D printing is directly connected to traditional construction techniques. For many years we traveled the globe to study architecture constructed of friable soils (mud brick, rammed earth, cob), which took us to Peru, Yemen, China, Argentina, and closer to home in the American Southwest. Based on this research, Ronald completed his first book in 2008, *Earth Architecture* (Princeton Architectural Press), which presented the most widely used building material on the planet—earth (soil, clay, gravel and sand)—as relevant to contemporary and modern architecture. In the books afterward, a future scenario for the material was proposed—one that would employ Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) processes. While it is commonly considered that digital manufacturing and earthen architecture exist at opposing ends of the technological spectrum, we embarked upon research to bridge the wide gap that exists between non-industrial, industrial and digital modes of production expanding on the benefits of each.

In 2009, an article appeared in Ceramics Monthly discussing the possibility of 3D printing with clay, authored by Professors Mark Ganter, Duane Storti and Bet Utela from the Department of Mechanical Engineering at the University of Washington.[[1]](#footnote-1) Professor Ganter had also begun to publish a series of open source recipes for 3D printable materials that he published on the website Open 3DP.[[2]](#footnote-2) It was through collaborations with Professor Ganter during this time that we experimented with several of these open source recipes and began to build upon these recipes and upon our own interests in certain materials, their sources, and cultural significance.

It is through the lens of 3D printing technology, coupled with an interest in craft traditions and place that our explorations in developing materials for architectural production began.

The computer and the 3D printer have allowed us to use particles of light, jets of water, and bits of data to transform dust into customized objects and products that serve as new building blocks for the future using materials that are locally available, inexpensive, derived from sustainable sources or waste streams, and can be upcycled or transformed into durable and beautiful architectural components that possess the possibilities of weathering, tactility and strength. The materials explored in this book: cement, sand, clay, salt, sawdust, coffee, tea, rubber, and others, are all materials that began in their powder form, and through the process of 3D printing, have emerged as a series of unique explorations that speculate about a 21st century architectural terroir that influences the crafting of objects and their meaning. [Figure 2]

Our research challenges the status quo of rapid prototyping materials by introducing new possibilities for digital materiality. For us, it is not solely the computational aspects that have potential for material transformation but also the design of the material itself. The nature of these materials; that they can be sourced locally (salt, ceramic, sand), come from recycled sources (paper, sawdust, rubber), and are by-products of industrial manufacturing (wood, coffee flour, grape skins), might situate them within the realm of “natural building materials”. However, the expansive and nascent potential of these traditional materials, when coupled with additive manufacturing, offers unnatural possibilities such as the ability to be formed with no formwork, to have translucency where there was none before, possess directed structural capabilities, and the potential for water absorption and storage. The material condition often referred to alternative, or “natural” building materials, are now unnatural building materials.

Turning the small into the big.

Considering the particle, the part, and their inherent possibilities, are not the only way we conceive of scaling up additive manufacturing. When we embarked upon this research, 3D printers were expensive and small. The largest 3D printers within a reasonable price range were designed to fit through a door or sit on your desk. This limits the size of the object that the 3D printer can produce. Rather than seeing this as a limitation to the production of architecturally scaled objects, we realized there are several advantages to printing smaller parts to create larger objects. The first is that 3D printing, despite existing for over three decades, is relatively new in the history of object making, and an imperfect technology. As most people who have worked with them before know, 3D printers often do not complete their task—it is a trial and error process that typically requires one to start over when there is an error in order to finish a print job. If a large printer is employed, and a print job requires hundreds of hours, a failed print would be a very time consuming endeavor. Rather, we have employed the notion of a “print farm”—a battery of many 3D printers each producing different parts. [Figure 3] If one printer fails, other printers can continue the task. In our farm, we grow larger structures from smaller 3D printed blocks, bricks, or tech-tiles. [Figure 4] The beauty of a large 3D printed structure built of hundreds or thousands of smaller non standard or customized components is that each part can be individually fine tuned to respond to the geomemetic particularities of a complex form. In this case, each component can acknowledge its position in space relative to the whole, by encoding the instructions directly onto the block and to external forces such as climate, solar orientation, and adjacent programming requirements.

This process of working from the small to the large, at times requires us to work backwards—from the large to the small, subdividing large constructions into their constituent printable parts. Because smaller parts are the scale of the hand, such as the bricks mankind has used historically to construct buildings and cities, they are easily handled and assembled, and also do not require special skills or tools for assembly, despite the complexity of the final outcome of an exuberant 3D printed structure. By 3D printing small, fundamental architectural components, we see the future of 3D printed architecture as accessible, interactive, and related to the craft traditions of the past, but with all the yet-to-be explored potential that this emerging technology has to offer.

3D Printing Architecture

Additive manufacturing will transform the way buildings are made. 3D printers allow architects to be material morphologists and it is a medium that ascribes value to design. Materials go in—and a product comes out. The driving factor in that process is design, which, as Andreas Bastian points out, integrates both quantitative and qualitative information, turning raw material into a valuable and meaningful object.[[3]](#footnote-3)

Whereas the traditional craft culture has a direct relationship between the craftsman, the material, and the product, the industrial revolution separated these relationships. Designers were not connected to the machine that made them nor the materials used in manufacturing. 3D printing, however, reconnects the designer to the material and the machine. In fact, the designer can design the materials, the machine, the software, and the product—expanding architects capabilities to have a more intimate relationship to the traditionally siloed fields that define design, visualization, structural optimization, budget and construction. 3D printing is also a potentially sustainable method of manufacturing. It can take advantage of local and ecological material resources, serve as a vehicle for upcycling, and produces very little waste when compared to subtractive methods of production. Another advantage of 3D printing architectural products is that they can be made on demand, so there is no surplus, no storage and no shipping products around the world - printed parts, or digital files, can be sent to job sites where components can be fabricated in-situ. In an era of disposable products, over consumption, excessive energy use, and toxic materials, architects have a responsibility to the public, and the planet, to change our mindset about what our buildings are made of and how they function, by engaging directly with the manufacturing processes used to construct architecture.

3D Printing Methods

There are many different methods of additive manufacturing but the three types used most frequently by Emerging Objects include: Binder Jetting, Fused Deposition Modeling and Paste Extrusion. We use these types of 3D printing technologies because the machines themselves are not designed for a specific material, only a material dimension, and that allows for material exploration and innovation.

Binder Jetting

Binder Jetting was invented at MIT in 1993. The process of printing using this technology consists of the spraying, or jetting, of a liquid binder material onto a thin layer of powder. The liquid binder solidifies the powder, and another thin layer of powder is rolled out over the top of the previous layer and the process continues hundreds, if not thousands, of times. Ultimately, after the 3D printed part is complete, the three-dimensional object must be excavated from the loose powder surrounding it. This loose powder also serves as support material, which allows for overhangs, undercuts and complex forms to be created. The object is then cleaned with a brush to remove the excess loose powder and the remaining powder is blown away or vacuumed off. The remaining powder can then be recycled and reused in subsequent prints, which means there is little to no waste. Printed parts can then be infused with a coating, or post-processed, to provide additional strength. Wax, low VOC epoxies, glues, and water can all serve as materials for strengthening binder jet printed parts—the selection of which depends on the material used and the application of the final product. [Figure 5]

Fused Deposition Modeling

Fused Deposition Modeling, or FDM, was developed byS. Scott Crump in the late 1980s and was commercialized in 1990. One of the advantages of 3D printing with an FDM printer is the relatively low cost and the fact that the parts do not need any post processing. Desktop printers are also very inexpensive as is the plastic filament used by the printers.

Fused Deposition Modeling is anadditive manufacturing technology commonly used for prototyping, but rarely for making final products. FDM works on the "additive" principle by depositing plastic filament along a predetermined path. For this to occur, plastic filament is unwound from a coil and supplied to an extrusion nozzle. The metal nozzle is heated and melts the plastic, which is then extruded through the nozzle and deposited onto a build platform. Printed objects using FDM methods are fabricated from the bottom up, one layer at a time. FDM is capable of dealing with overhangs by the support from lower layers but large overhangs and cantilevers require a printed scaffolding that anticipates any overhangs and supports them when the print arrives at that layer. [Figure 6]

Paste Extrusion

Paste extrusion is rapidly becoming a very accessible means of 3D printing very diverse materials. Quite simply, this is a process where a paste, stored in a tube, is pushed through a nozzle and onto a build platform. The paste is pushed either through compressed air, or a syringe or ram press. This is suitable for materials as diverse as cement, clay, play-doh, silicone, resin, frosting, UV paste, mashed potatoes, chocolate, and many others. The process of extruding a line of paste onto a build bed is very similar to traditional FDM methods of printing except that the material is not being heated in the nozzle. Like FDM, the parts are also built from the bottom up, one layer at a time. Currently, the diameter of paste extrusion can range in size anywhere from .4 mm for bio inks used in the extrusion of cells for organs to 25 cm wide used for extruding mud and concrete to make entire buildings. [Figure 7]

There are several early users of computer numerically controlled (CNC) paste extrusion; including Adrian Bowyer in 2005 who started the RepRap project with a paste extruder before filament extruders became commonplace, Behrokh Khoshnevis, who had developed a contour crafting machine that extruded cement in the late 1990’s, and Evan Malone and Hod Lipson, who released the Fab@Home multi-material 3D printer in 2006. But it was not until 2009, when Dries Verbruggen, of Unfold Design Studio, rapidly advanced paste extruding through the invention of the “claystruder”, which he used for 3D printing clay, that paste extrusion became attainable and visible to a larger audience. Over the last 10 years, clay extrusion has become very popular due to the low cost of the material itself, the low cost of the machines and the durability of the clay once it has been fired in a kiln. Additionally, there are many open source kits for building clay 3D printers available online and there is no waste, since all of the leftover, dried clay can be reused.

Project Credits:

 Bad Ombrés, Wursterware

Project Team: Ronald Rael, Virginia San Fratello, Phirak Suon

Technical Assistance: Ehren Tool, Nicki Green (Wursterware)

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Bloom

Project Team: Ronald Rael, Virginia San Fratello, Kent Wilson, Alex Schofield, Sofia Anastassiou, Yina Dong, Stephan Adams, Alex Niemeyer, Ari Oppenhiemer, Reem Makkawi, Steven Huang

Cement Material Development: Ronald Rael

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Burst Tiles, Burl Bowl, Chardonnay Wine Goblets, FLO, Finger Tiles, Grab Tiles, Ombre Decanters, Romanescos, Salt Shakers, Sugar Sugar Spoons, and the Utah Tea Set

Project Team: Ronald Rael, Virginia San Fratello

Wood, Chardonnay, Salt, and Tea Material Development: Ronald Rael, Virginia San Fratello

Coffee Coffee Cups

Project Team: Ronald Rael, Virginia San Fratello, Alexander Schofield, Kent Wilson

Coffee Material Development: Ronald Rael, Alexander Schofield

Coffee Cherry Material Development: Ronald Rael, Virginia San Fratello

Cool Bricks

Design Team: Ronald Rael, Virginia San Fratello.

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Drum, Haeckel Bowls, Lamprocyclas Raelsanfratellis, Rocker Vases, Starlight, The Berkeley - Rupp Prize, Twisting Tower

Project Team: Ronald Rael, Virginia San Fratello, Kent Wilson

Wood, Chardonnay, Rubber and Salt Material Development: Ronald Rael, Virginia San Fratello

Earthscrapers

Project Team: Ronald Rael, Virginia San Fratello, Maricela Chan, Chris DeHenzel, John Faichney, Emily Licht

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GCODE.clay

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Project Team: Ronald Rael, Virginia San Fratello, Kent Wilson

Salt Material Development: Ronald Rael, Virginia San Fratello

Design: Thom Faulders of Faulders Studio.

Hairline Drawings, The Damask Wall

Project Team: Ronald Rael, Virginia San Fratello, Barrak Darweesh

Involute Wall, Quake Column and Picoroco Wall in Sand

Project Team: Ronald Rael, Virginia San Fratello

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Marc Metamorphosis, Scin Cube, Seed (P\_Ball)

Project Team: Ronald Rael, Virginia San Fratello, Kent Wilson

Cement Material Development: Ronald Rael

Chardonnay Material Development: Ronald Rael, Virginia San Fratello

Design: Andrew Kudless of Matsys.

Newsprint

Project Team: Ronald Rael, Anthony Giannini

Newsprint Material Development: Ronald Rael, Anthony Giannini

Picoroco Wall in Orange

Project Team: Ronald Rael, Virginia San Fratello, Seong Koo Lee

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Planter Bricks

Project Team:  Ronald Rael, Virginia San Fratello, Molly Reichert

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Planter Tiles

Project Team:  Ronald Rael, Virginia San Fratello, Kent Wilson, Alexander Schofield.

Cement Material Development: Ronald Rael

Poroso

Project Team: Ronald Rael, Virginia San Fratello, Molly Wagner and Victoria Leroux

Wood Material Development: Ronald Rael, Virginia San Fratello

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Project Team: Ronald Rael, Virginia San Fratello, Voung Dao

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Cement Material Development: Ronald Rael

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Project Team:   Ronald Rael, Virginia San Fratello, Kenneth Wilson, Alexander Schofield, Phirak Suon.

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The Primitive Huts

Project Team:  Ronald Rael, Virginia San Fratello, Kent Wilson, Alexander Schofield.

Wood Blocks

Design: Anthony Giannini

Wood Material Development: Ronald Rael, Virginia San Fratello

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—Ronald Rael & Virginia San Fratello, 2017

1. Mark Ganter, Duane Storti and Ben Utela, “The Printed Pot”, Ceramics Monthly, (Feb.,2009): 36. [↑](#footnote-ref-1)
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