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To Nana Jaan, the kindest grandfather and the utmost skilled artisan, who passed away during the preparation of this dissertation 29/03/2019

To Dada Jaan, whome I never met in person but through the incredibly inspiring stories of many

Both have instilled within me a passion for kindness and a curiosity for innovation.

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Abstract

Mass production and assembly lines are yesterday's manufacturing methods. They have exhausted Earth's resources and limited the possibilities of design in terms of both form and material, prompting designers to search for new processes. A new generation of making includes biomimicry-inspired technologies such as 3D printing and parametric simulation, which have transformed the production paradigm. Utilizing nature as industry, this thesis explores the possibility of "growing" designed objects by employing nature's own processes and resources. It integrates bio materials, generative design and additive manufacturing to produce objects for a post-industrial world. The project outcomes employ natural minerals, crystallization and 3D printing to develop new forms of making, proposing a new suite of tools for designers.

INTRODUCTION

Two contrastingly distinct generative cultures exist in the world: natural and man-made. The former is created by, or derived from, nature and is comprised of organic and progressively generated objects, patterns, processes and systems; the latter is deliberate, forced, and—since the industrial revolution—reliant upon mass production to produce standardized objects. In the natural world, organisms grow naturally through single cell metamorphosis, generating complex forms and performing complex functions. A plant's future growth is embedded in the DNA of its seed. The seed carries all of the information required for the plant to function, replicate, and multiply.

By contrast, in the man-made world, objects are manufactured from synthetic parts, which must be assembled manually. Since the start of the industrial revolution, the man-made world has been shaped by manufacturing, mass production and assembly processes that condition designers to perceive objects as assemblies of discrete parts with distinct functions. Assembly lines drive the manufacturing of objects, dictate a world made from parts, and produce systems of highly specific materials, creating complex supply chain networks. This rigid paradigm results in predictable forms, predetermined functions and a process that discourages variation. Consider the production of a wooden chair, for example. It commences with the harvest of raw material: say, a 60-year-old tree that has been carefully selected, transported to a workshop, and cut into blocks. These blocks of wood are milled into chair parts using tools and equipment, and then joined together to form the chair. When a chair is mass-produced, this process, which involves subtractive manufacturing, includes multiple stages of cutting, removing material, and reshaping, creating waste at every step. Though mass-manufacture successfully meets production goals, it depletes Earth's natural resources and contributes to pollution by producing by-products such as bio-chemicals and harmful gases, contaminating the environment and negatively impacting humans and the environment.

Seeking alternatives, Neri Oxman, a renowned architect, designer, and MIT professor, explores design at the intersection of technology and biology. She argues designers must unite technology with synthetic biology, a field of science that utilizes the power of nature to create and solve problems. The unification of design, biology and technology is leading to new forms of additive manufacturing

and innovations to 3D printing technologies. Although the design world and the natural world can be described as two opposite extremes, they coexist simultaneously. In this context, design and nature can be viewed as a paradox of unity and duality. They can be expressed as opposite forces, but opportunities arise, instead, from focusing on their complementary attributes. As we move forward, in the midst of new developments and breakthroughs in manufacturing capability and accessibility to additive 3D printing technologies, designers have an opportunity to learn from the natural world to produce design processes and outcomes that are more flexible and unified in terms of form, material and function.

By combining natural materials and processes with the benefits of additive manufacturing, this thesis research proposes an alternative additive manufacturing process able to "grow" designed products. This research explores the fusion of natural and man-made manufacturing processes to benefit from the best of both.

BACKGROUND

Figure 01 Ford Assembly Lines



Literature Review

The Industrial Revolution transformed rural, agrarian economies into ones built on mass production by exploiting and consuming non-renewable resources, and developing new products to meet exponential growth in consumer demand. Mass production fueled the Industrial Revolution and marked a shift in the manufacturing paradigm. Although the idea of mass production existed previously, Henry Ford's introduction of the Ford Moving Assembly Line at Highland Park, near Detroit, Michigan, revolutionized industrial production, spawning widespread imitation and exponential growth that reached its peak by the end of World War II, as consumer demand exploded.¹ Mass production was made possible by the standardization of interchangeable parts and moving assembly lines, meaning far greater numbers of products could be made for less cost. Initially, consumer choice offered by such a production paradigm was limited, as reflected in Ford's famous statement: "Any customer can have a car painted any color that he wants so long as it is black."² Manufacturers produced products based on production ease rather than consumer preference. In the article, "Evolving Paradigms of Manufacturing: From Mass Production to Mass Customization and Personalization," Jack Hu states, "In fact, many U.S. manufacturers had forgotten their customers and the quality of products had deteriorated."³

Principles set forth by pioneers like Ford, during the industrial revolution, still reverberate in contemporary design practice. According to Neri Oxman, the world of design is still dominated by the values and manufacturing constraints of mass production:

Assembly lines have dictated a world made of standard parts framing the imagination of designers and builders who have been taught to think about their design objects and systems in terms of assemblies of parts with distinct functions. The assumption that parts are made of a single material and fulfill predetermined specific functions is deeply rooted in design and usually goes unquestioned; it is also enforced by the way that industrial supply chains work.⁴

The development and proliferation of mass production has relied heavily on consumption of non-renewable fossil fuels to increase output. The economy of consumerism has supported the growth of larger and ever more efficient factories, which has in turn contributed to environmental damage caused by these industries.⁵

The environmental cost of this culture has led some in industry to take a proactive role in developing alternative processes that are pollution preventive. Concern regarding shortages of energy and raw materials has stimulated designers to explore production alternatives inspired by nature. By utilizing nature as industry, is it possible to develop alternative modes of production? Can products be grown, rather than manufactured? Can products be an extension of the environment? After all, Leonardo da Vinci told us, "Go take your lessons from nature, that's where our future lies."⁶

Threats from climate change, caused by increased greenhouse gas emissions, including loss of biodiversity and exhaustion of fossil fuels, has recently inspired a robust ecological movement. This groundswell of public opinion promises to re-chart the course of the modern industrial economy, leading to breakthrough technical solutions and dramatic changes in the way consumer products are produced. Public demand for more sustainable systems and products promises a new approach, inspired by nature.⁷

Biomimicry is an ecological movement popularized by Janine Benyus, an American biologist and author of *Biomimicry: Innovation Inspired by Nature*.⁸ Benyus is specifically interested in analyzing ways nature can inspire designers. She suggests three ways to think about biomimicry: mimicry of form, mimicry of pattern, and mimicry of ecosystem. First, a design can mimic form or structure; for example, the nano-structure surface of a self-cleaning paint coating, inspired by the water-repellent properties of the lotus leaf. Second, the pattern of communication used by an autonomous vehicle network, which benefits from studying how bees communicate within the hive. Third, the no-waste efficiency of the forest nutrient chain, which inspires the notion of Circular Economy. "Ecosystems do that really well," explains Benyus. "You've got a log on the forest floor, and those materials move up into the body of the fungus that eats it, and that mushroom is then eaten, and those materials move up into a mouse, and that mouse material moves up into a hawk."⁹

Biomimicry seeks to adapt models, systems and elements of nature to resolve complex human problems. For more than 3.8 million years, natural systems have been developing and evolving on Earth; however, it is only recently that designers have begun to tap the latent potential in this vast body of research and knowledge as design precedent. The ultimate aim of biomimetic design is to make products and cities emulate systems, materials and forms from nature. In her article, "Product and Technology Innovation: What Can Biomimicry Inspire?" Elena Lurie-Luke discusses a rising interest in biomimicry amongst leading research institutions such as MIT. According to her, this has provided fertile ground for innovation throughout many fields, such as architecture, engineering and medicine.¹⁰

Figure 02 Biomimicry: Japanese bullet train mimicks kingfisher beak to reduce noise



Neri Oxman, founder of Mediated Matter research group at MIT, conducts research with her team at the intersection of computational design, digital fabrication, materials science and synthetic biology, with the goal of enhancing the relationship between the built, natural, and biological environments.¹¹ Her research has application in product design, architectural design and fashion design. Additionally, Oxman coined the term Material Ecology, which she defines as the study and design of products and processes that integrate environmentally aware computational form generation and digital fabrication. This approach views both material and object as extensions of the natural environment.¹²

Material Ecology employs multifunctional materials like silk, which can be interwoven with a single filament to seamlessly become both an enduring load-bearing wall, and a floor surface soft enough to walk on barefoot. This remarkable range is made possible by ultra-high-resolution manufacturing and sophisticated computational algorithms. It considers computation, fabrication, and the material itself as inseparable dimensions of design. "In this approach, products and buildings are biologically informed and digitally engineered for, with, and by Nature."¹³ Oxman's work showcases organic forms that highlight the potential of generative design to replace the modular design inherited from mass production. In the book *Generative Art*, Matt Pearson distinguishes between the organic and the mechanical world:

According to Alan Watts, a prominent British-American philosopher, natural forms are not made but grown, and there is a radical difference between the organic and the mechanical. Things which are made, such as houses, furniture, and machines, are an assemblage of parts put together, or shaped, like sculpture, from the outside inwards. But things which grow shape themselves from within outwards—they are not assemblages of originally distinct parts; they partition themselves, elaborating their own structure from the whole to the parts, from the simple to the complex.¹⁴

The process of design in nature is organic, adaptive and ever-evolving. In nature the growth of a tree or a flower is determined by set parameters such as seed, soil, air, and temperature, which work together, yielding unique and random patterns of growth and evolution. Likewise, generative design imitates nature's organic forms by controlling digital parameters to generate complex variations of parametric forms. Digital software, such as Processing, Python and Grasshopper, work with programming codes, which can be adjusted to achieve the complexity found in nature's organic forms. This software can also connect to real time data, to generate forms from natural stimuli, such as sunlight intensity or humidity levels. The intricate forms, which are generated digitally, can only be fabricated using additive manufacturing, where objects are created by depositing material layer-by-layer.

According to the *World Economic Forum*, additive manufacturing or 3D printing—also described as the Fourth Industrial Revolution—has become one of the most efficient and practical prototyping tools in support of product development.¹⁵ In the article "Five Million Jobs by 2020: the Real Challenge of the Fourth Industrial Revolution," author Oliver Cann writes, "This fourth industrial revolution is essentially reinventing how goods are manufactured and distributed."¹⁶ 3D printing via extrusion—in which material is deposited layer-by-layer—incrementally forms a solid object with minimal material and energy. By easing access to 3D printing and bringing manufacturing to the desktops of everyday users, this technology has revolutionized conventional manufacturing by reducing the gap between production and consumption. 3D printing allows users to take charge of their designs, share them on digital platforms, and customize products.

Rapid advancement in the development of additive manufacturing technology has produced breakthroughs in the fields of healthcare, aerospace and education.¹⁷ Additive manufacturing resembles natural growth in the sense that it slowly builds an object, layer-by-layer. By integrating natural materials and processes with additive manufacturing, this thesis proposes a hybridized process for producing objects in a post-industrial world.

Figure 03 3D Printer extruding PLA



PRECEDENTS

Saltygloo by Emerging Objects

Emerging Objects is a 3D fabrication studio run by Ronald Rael and Virginia San Fratello, which creates specialized solutions for building components and architectural structures.¹⁸ The studio combines various 3D printing processes with uniquely engineered materials to create large-scale innovative objects.

Saltygloo combines 3D printed materials with local salt, harvested from the San Francisco Bay, to print large structures. *Saltygloo* is a room-sized self-supporting structure, built from 336 translucent panels made from salt mixed with glue, forming "salty glue," a material that is extruded and deposited using a 3D printer.¹⁹ The translucent panels are assembled into a shell, inspired by the Inuit Igloo, using lightweight aluminum rods for stability. The local salt, made by moving saline water through a series of evaporation ponds, possesses unique lightweight properties, making it possible to produce the translucent material capable of dispersing natural light shown in Figure 4. The innovative project demonstrates how additive manufacturing processes, combined with naturally produced crystals, can produce structural solutions.

Figure 04



Figure 05



Vegan Design by Erez Navi Pana

Erez Nevi Pana is an Israeli designer who experiments with materials and natural processes to produce animal-free furniture. In Pana's exhibition *Vegan Design*, he critiques the cruelty of animal-based products, using plant- and mineral-based alternative ingredients.²⁰ He provides the design industry an approach to implement vegan materials, to produce sustainable design outcomes.

According to Pana, each object in his exhibition is a product of experimentation with vegan materials such as soil, salt, clay and textiles. He states, "It is not aesthetic or about function, it is a placid theory that can turn explosive."²¹ His research explores natural material formation in the Dead Sea. He initiates the design process by fabricating wooden stools and then submerges them in the Dead Sea's highly saline water. The stools, remaining in seawater for several months, get covered by thick layers of crystallized salt.

His work also includes vegan furniture made from wood scraps he gathers from carpenters. He joins the scraps using vegan glue, made from a mixture of plant fibers and natural resin. Pana also produces non-functional products that highlight the abundance of natural materials like salt, using the process of crystallization to create unique and organic skins around everyday products. Pana's work showcases the potential of using materials from the natural environment to form unique and generative outcomes that can inform alternative ways of making everyday products.



Figure 06

Figure 07



The Solar Sinter by Markus Kayser

Markus Kayser's multidisciplinary work is inspired by questioning the future of fabrication in a world of depleting resources. Kayser's projects merge technology, design and biology to develop functional tools that are used to create designed outcomes.

The Solar Sinter is a 3D printer, designed by Kayser, that uses sunlight energy to melt sand—an abundant material—into glass.²² The machine uses a Fresnel lens, light sensors and solar-powered motors to produce objects. The Fresnel lens focuses sunlight, raising the temperature to 2900 degrees Fahrenheit.²³ The machine contains a box, filled with sand, which is placed under the lens. Light sensors, connected to solar-powered motors, track the sun's movement, assuring the lens produces an optimum concentration of heat. A computer controls the pathway, based on an uploaded design file, guiding the solar-powered motors. After each pass, a new layer of sand is sprinkled over the melted glass, and then the process repeats until all layers have been melted, forming the final glass object. The finished object is removed from the sandbox once it cools.

The formal and aesthetic quality of these objects depends on the sand's properties and can vary from one batch to the next. Each printed object has a unique and distinctive texture, color and scale. The approach provides useful insight into production processes using context-specific material.

Figure 09

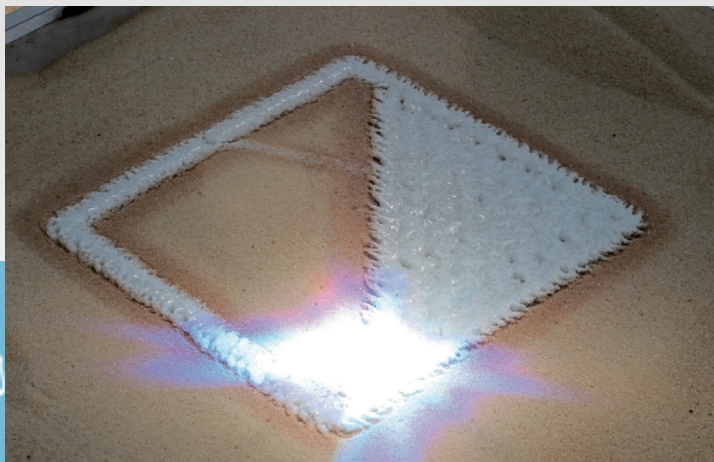
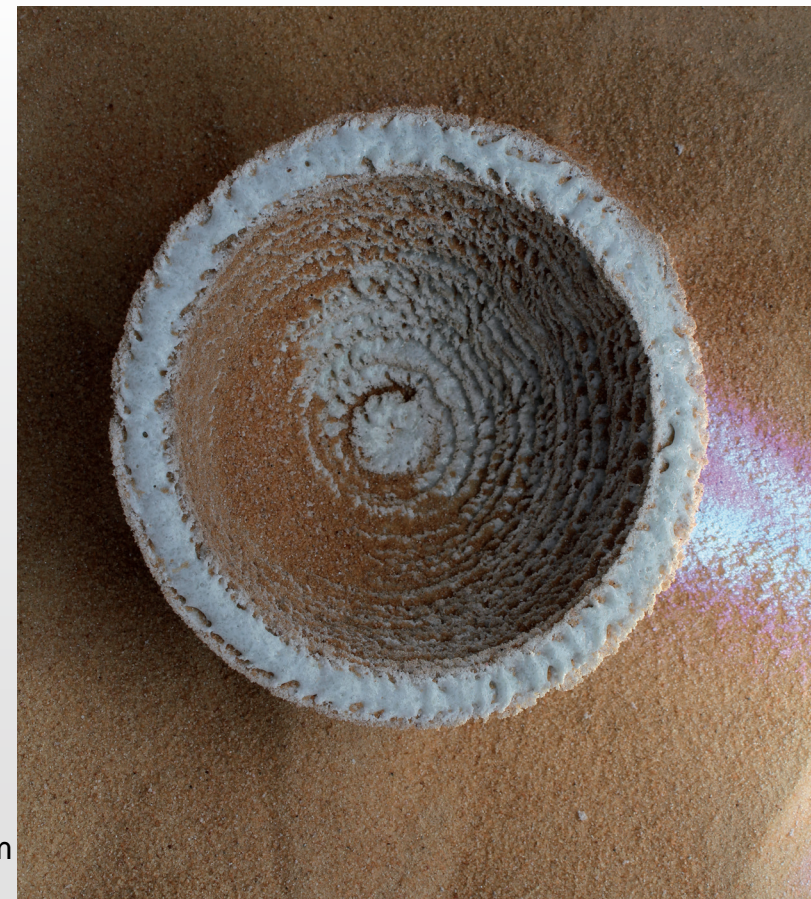


Figure 08



Figure 10



The Silk Pavilion by MIT

The Silk Pavilion is a project by the Mediated Matter Group of MIT Media Lab. The project fuses biological and digital fabrication processes to generate a large-scale object. The process is inspired by the silkworm's ability to generate a cocoon from a single silk thread.

Tiny magnetic sensors were placed on silkworms to capture their movement while weaving a cocoon. The movements generated an algorithm, which produced the pavilion's geometry.²⁴ Researchers analyzed the environmental and spatial habits of silkworms, and found they are attracted to darkness, meaning they create more densely woven sections where there is less light. Solar mapping—a process of measuring sunlight intensity on surfaces—was used to map natural silk structures, to assess variation of material, size, density and aperture size. To translate this natural process into a larger project, a robotic arm was programmed to imitate the silkworms' movement. The robotic arm deposited a thousand meters of silk fiber across flat, polygonal, CNC - cut metal frames. The final outcome was constructed of 26 polygonal panels assembled into a dome suspended from the ceiling. A swarm of 6,500 silkworms then deposited a second layer of silk.²⁵ The Silk Pavilion pushes the boundaries of technology, imitating the intricate movements and processes of nature to create large architectural systems.

Figure 11

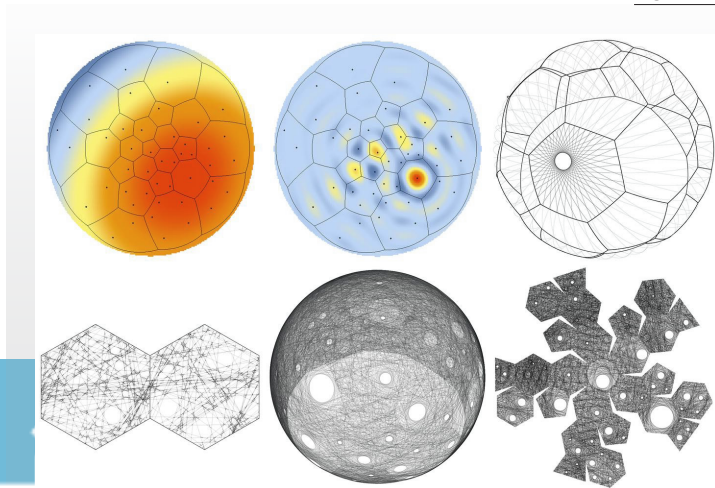


Figure 12



Figure 13

Full Grown by Gavin Munro

Gavin Munro is a British designer and carpenter who has developed an unconventional process for growing furniture. By manipulating and molding live willow trees as they grow, he forms unique chairs, lamps, and tables. He has challenged traditional ways of manufacturing furniture using the concept he calls "Zen 3D printing," a form of organic 3D printing that utilizes soil, air, and sunshine.²⁶ His work is inspired to find a role for nature in the future creation of sustainable and efficient products.

He has created an open-air factory, strategically planting trees, grafting and adapting them into furniture. Designed structures support the limbs as they grow, and grafts are added strategically to guide the tree branches as they slowly bend and stretch into the desired shape. Willow crops are hardy, fast-growing, cost-efficient, require little water, and are easy to work with.

Munro's project emphasizes the importance of time and process. Hacking into nature's biological process takes time and cannot be rushed. The natural process must be studied carefully, to produce sustainable, efficient outcomes. Munro has studied variables that affect growth, like time, and has used this knowledge to hack natural growth into unique organic sculptures. He has capitalized on this simple, but effective concept and currently has a 50-year plan to continue the production at a global scale.²⁷ His innovative approach to designed natural growth has potential to revolutionize the future of everyday product design.

Figure 14



Figure 15

Figure 16



CONCEPTUAL FRAMEWORK

My thesis research combined two key processes: natural crystallization, and 3D printing. This combination informed the conceptual framework, preliminary exploration and final outcomes. Together, I was able to pair nature's own 3D generation technique—mineral crystallization—with the digital control of 3D printing, to develop new fabrication possibilities.

SALTY SITUATIONS

Figure 17 Desert Rose

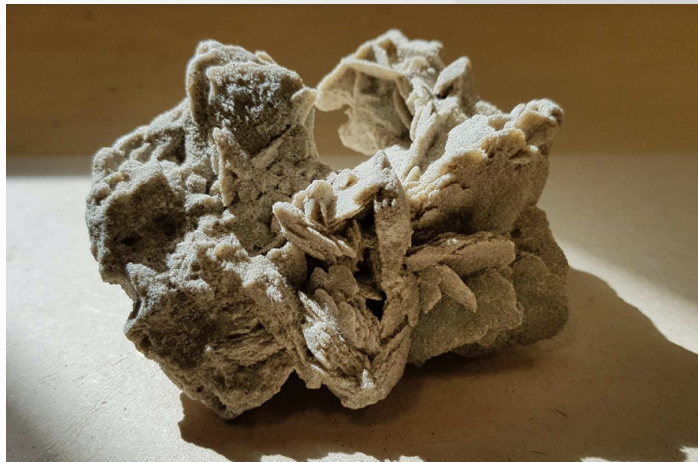


Figure 18 Mixed mineral salts



Figure 19 Natural mineral and concentrated solution



Preliminary Exploration

The desert rose is a beautiful cluster of crystals naturally occurring in Qatar's arid environment. Desert roses result from crystallization, which occurs when shallow saline water evaporates, forming clustered crystals composed of natural minerals and sand.²⁸ Crystallization, which takes place incrementally, a bit at a time, is nature's additive manufacturing process. My developing understanding of this natural process, combined with my interest in digital 3D printing, led to my proposal for a new generative methodology, combining 3D printing and natural crystals to develop functional products. Over the course of extensive experimentation, I identified several key parameters: mineral selection, solution preparation, and selection and structural configuration of an underlying host material. My investigations followed a series of controlled experiments, with a flexible timeline, driven by the nature of crystallization.

Mineral Explorations

In nature, crystals form very slowly, under extreme conditions, such as high pressure and drastic temperature change. The specifics of these conditions control the shape, color and geometry of crystals.²⁹ For this reason, it was important for me to systematically vary the ratio of ingredients in the mineral solution, to gain an in-depth understanding of the conditions that drive the crystallization process. Through methodical experimentation, I tested a range of minerals, including local saltwater, table salt, Epsom salt, alum, and Borax. My experiments tested for time of formation, strength, translucency and ability to adhere to a host material. Alum and Borax emerged as far and away the most successful minerals, as they formed the quickest, most robust, and most translucent crystals, while most uniformly coating the 3D printed PLA host structure.

Host Materials

Following experiments designed to assess the characteristics of mineral, it was important to test the ability of crystals to form on various materials. I tested various natural and synthetic materials, with consideration given to biodegradability, ability to form into parametric structures, and capacity to support uniform crystal growth. Sample natural materials included thread, paper, metal and wood. I also tested synthetic materials including pipe cleaners, LDPE Plastic and PLA plastic. Thread supported uniform growth, due to its porous, rough surfaces. But in terms of the flexibility offered to me, as a designer, PLA emerged as the ideal host material, because it is biodegradable, lightweight, and its compatibility with conventional 3D printing technology that allows it to be configured into any three-dimensional form.

Structures

Having selected the host material, I researched structural systems inspired by nature that could optimize crystal growth. I experimented with wireframe structures, meshes and lattice structures, searching for a self-supporting method capable of promoting uniform crystal growth. I iteratively tested options, working to utilize the least amount of material possible, by eliminating unnecessary support, without sacrificing stability. Lattice structures proved the most successful, designed and printed to minimize material quantity, while providing optimal spacing for the growth of alum and Borax crystals.



Figure 19 Crystal formation on PLA, Natural fibers, wood, steel and pipe cleaners

Figure 20 Successful crystal growth on 3D printed Lattice structure



CRYSTAL CLEAR

Findings

Analyzing the results of numerous controlled experiments, I identified the ideal minerals, host materials and structural configurations needed to demonstrate the potential of merging these two generative processes—3D printing and natural crystallization—to produce a functional product. Leveraging the benefits of natural crystals—their translucent, multifaceted surface, their ability to encapsulate a minimal lattice structure and add rigidity—combined with the benefits of 3D printing—formal liberty, speed of production, accessibility, low cost—I arrived at the decision to design a line of light fixtures. The chosen project showcases the way the translucent crystals naturally refract and diffuse light, highlighting the beauty of the material. Even unlit, the crystals reflect incidental light, casting an alluring luster born of the complex geometry inherent to each individual crystal formation.



Figure 21 Crystals reflecting light



Figure 24 Crystals diffusing light



Figure 22 Crystals reflecting light



Figure 25 Crystals diffusing light

OUTCOME

A critical reaction to the limitations of mass production, this project proposes a new manufacturing methodology, combining materials and processes from nature with emergent fabrication technology, to develop products for a post-industrial world. It combines two generative processes—3d printing and mineral crystallization—to develop a unique, modular light fixture.

Following a biomimetic approach, the base structure consists of frames derived from the perfect octahedral geometry of the alum crystal. These octahedral frames house triangular lattice panels, which are parametric simulations of crystal lattice structures—the three-dimensional arrangement of atoms within crystals. The orderly behavior and systematic arrangement of atoms in the crystal lattice informs the design's modularity and adaptability. Frames and panels are 3D printed with customized settings, designed to achieve precision and strength, while using the least amount of material possible. Each octahedral frame is an identical unit, designed for attachment to other frames and lattice panels. The modular capacity allows each lamp to grow incrementally, much like a crystal. The configuration of frames and panels can be arranged as needed. Seven lattice panels attached to a single frame make a desk lamp. Alternatively, more frames and panels can be joined to form a suspended ceiling fixture, or combined and built up from the ground to form a floor fixture.

Once the lattice panels are 3D printed, they are suspended in a heated solution of concentrated Borax. Over time, as the temperature cools, the Borax crystals begin to grow, encapsulating the 3D printed lattice panels. The accumulating crystals are nature's 3D print, forming a thick translucent skin, gradually filling voids in the triangulated lattice panels. Due to the unpredictable, organic nature of the crystal growth process, nature determines the light fixture's final shape. Each lamp has a uniquely distinctive form, based on the color, texture and size of a given batch of crystals. The translucent crystals diffuse and scatter light from the internal light source, filling the surrounding space with a soft ambient glow, and creating a sense of quiet majesty. The final product combines industrial precision with the authentic, organic variety of nature.

Figure 26 3D printed triangular lattice panels with PLA, Crystal growth on triangular lattice panel

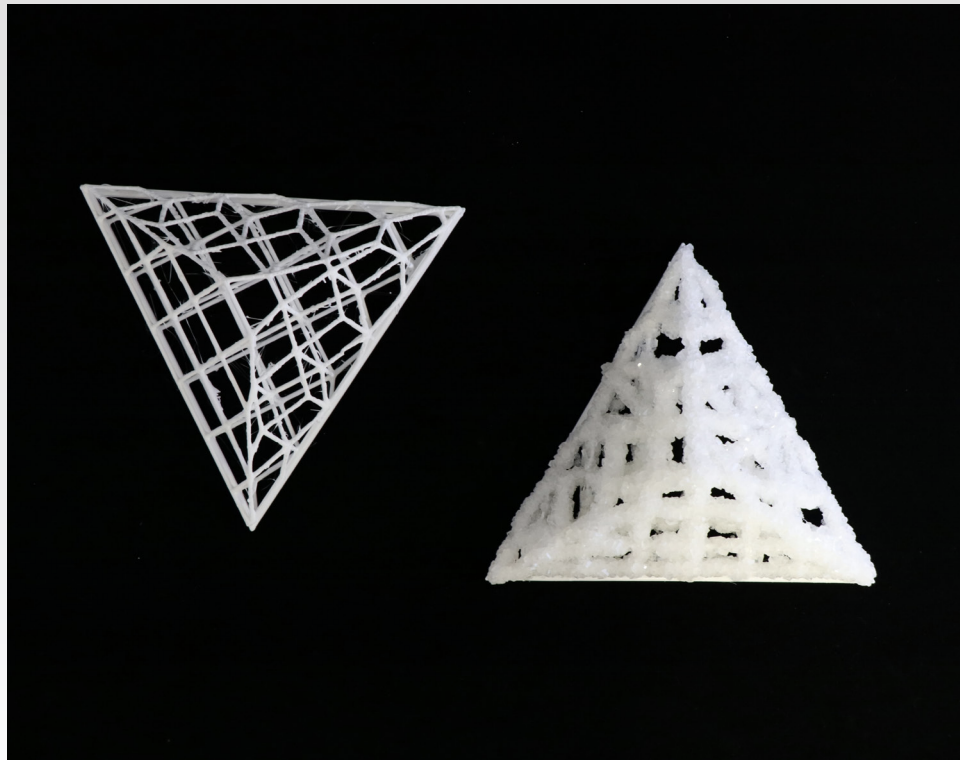


Figure 27 Octagonal frame

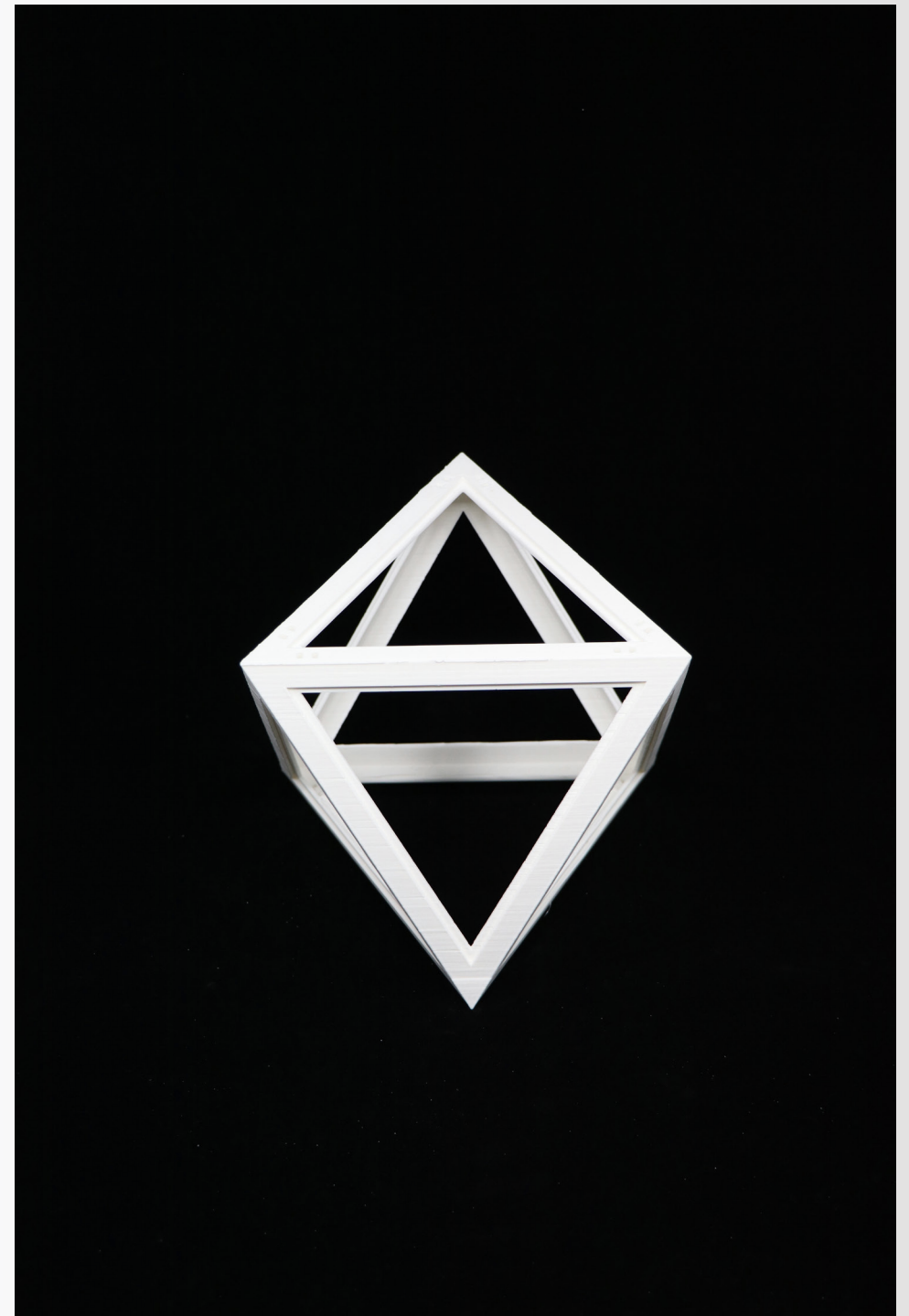


Figure 28 Octagonal frame

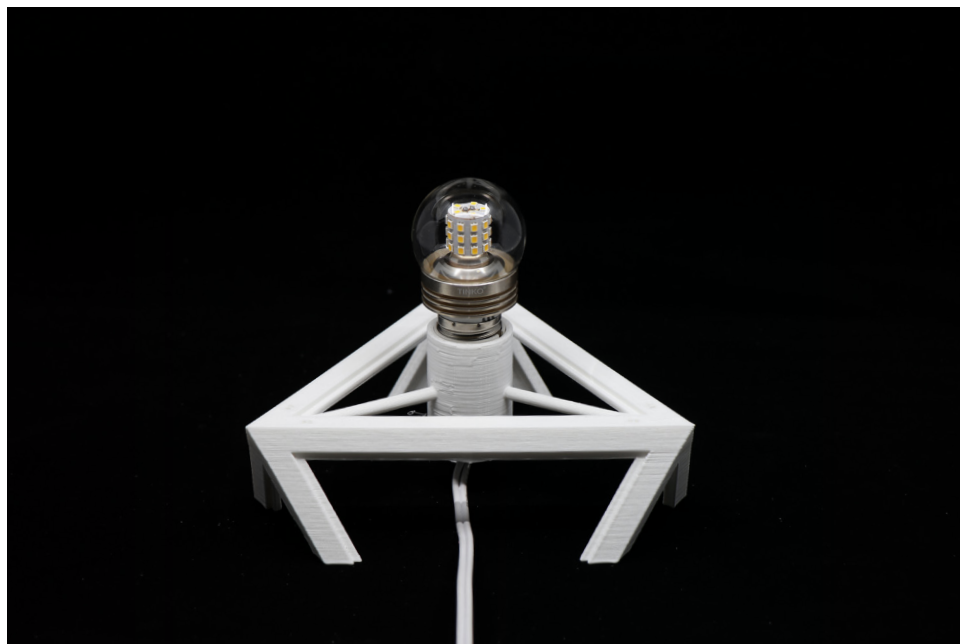


Figure 29 Octagonal frame

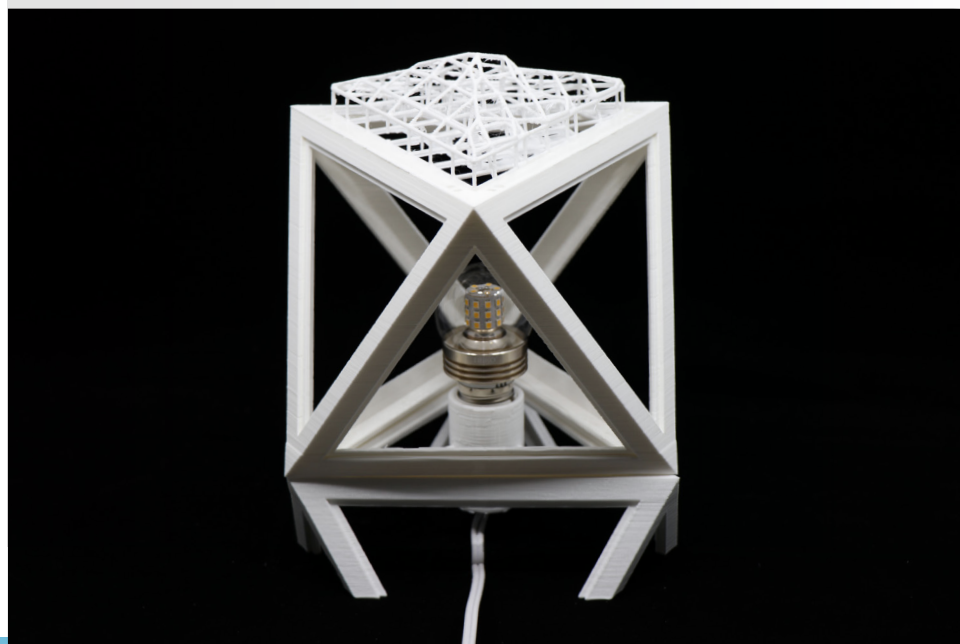


Figure 28 Octagonal frame

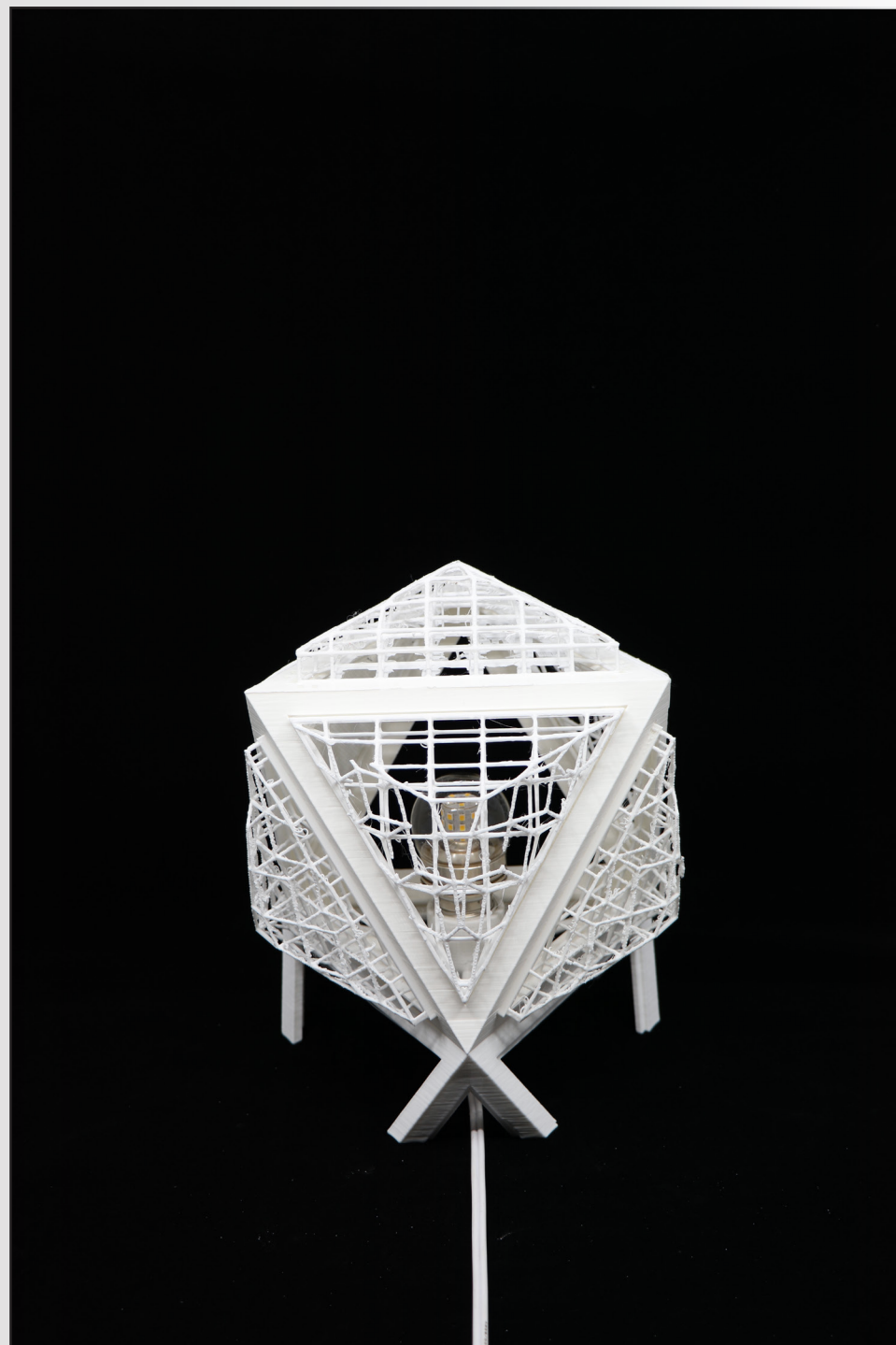
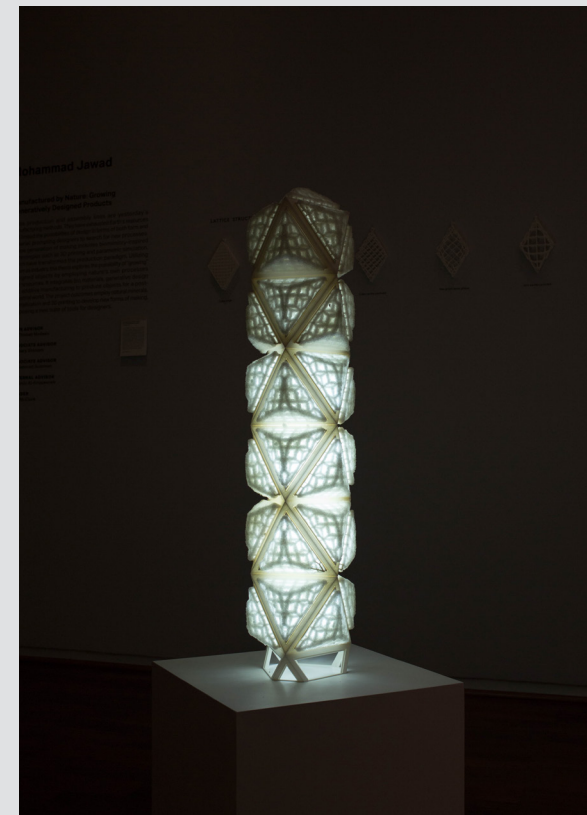


Figure 31 Crystallized table lighting fixture without light



Figure 32 Crystallized table lighting fixture with light





CONCLUSION

Manufacturing methods developed during the industrial revolution continue to harm the global ecology and restrict the possibilities of design, conditioning designers to accept unnecessary limitations. Seeking new alternatives, this thesis utilizes the industry of nature to pair natural materials and processes with the emergent potential of 3D printing, to "grow" objects for a post-industrial world.

The underlying conceptual framework combines two generative methods: naturally formed mineral crystals, and 3D printing. Powered by parametric digital models, the resulting project benefits from the digital control of 3D printing—produced with technology, but inspired by the logic and efficiency of nature's forms—and also the organic variety and no-two-pieces-alike authenticity of natural crystallization. Both aspects follow nature's method of gradually adding material, layer-by-layer, to form a hybrid end product. To arrive at my production methodology, I first investigated a range of mineral solutions, host materials and support structures, to find the best proposal for creating generatively designed products. This experimentation phase was crucial, as it paved the way for the applied design research demonstrated in my final outcome.

The result is a series of modular light fixtures, a project which proposes a new pathway to product development and production. The approach highlights nature's process of patient, incremental growth, and demonstrates a new way to produce environmentally friendly products. The outcome balances the precise, controlled, flexibility of industrial 3D printing, with the naturally distinctive growth of crystals—hybridizing mechanical assembly and organic growth. By employing natural growth as part of the process, each lamp is inherently unique, defying the expectation of banal repetition inherited from mass production and the industrial revolution. A defining goal of this thesis, therefore, is to challenge the preconceptions of designers and offer an alternative vision for the future of design.

FUTURE DIRECTION

Following this process of extensive experimentation, where I examined the balance between humble natural materials and emergent technology, the future seems bright. I foresee many possibilities for taking this research further. I imagine taking steps to scale up, to develop an industry that utilizes "Quasicrystal Printing," to grow jewelry, furniture and fixtures, clothing, and more. I would also like to explore ways of using crystals to reinforce and add structure to malleable materials like natural fibers. I imagine exciting furniture-scale possibilities, involving the immersion of fabric constructions into saturated solutions, using crystallized coatings to add strength and structural capacity. The possibility of hybridizing natural processes with digital fabrication provides a point of departure for fresh thinking, opening new possibilities for the future of design and production.

EXIBHITION



MFA IN DESIGN

Mohammad Jawad

Manufactured by Nature: Growing Generatively Designed Products

Mass production and assembly lines are yesterday's manufacturing methods. They have exhausted Earth's resources and limited the possibilities of design in terms of both form and material, prompting designers to search for new processes. A new generation of making includes biomimicry-inspired technologies such as 3D printing and parametric simulation, which have transformed the production paradigm. Utilizing nature as industry, this thesis explores the possibility of "growing" designed objects by employing nature's own processes and resources. It integrates bio-materials, generative design and additive manufacturing to produce objects for a post-industrial world. The project outcomes employ natural materials, crystallization and 3D printing to develop new forms of making, proposing a new suite of tools for designers.

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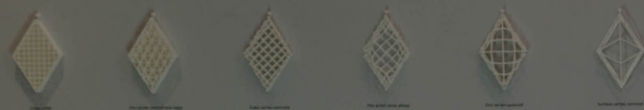
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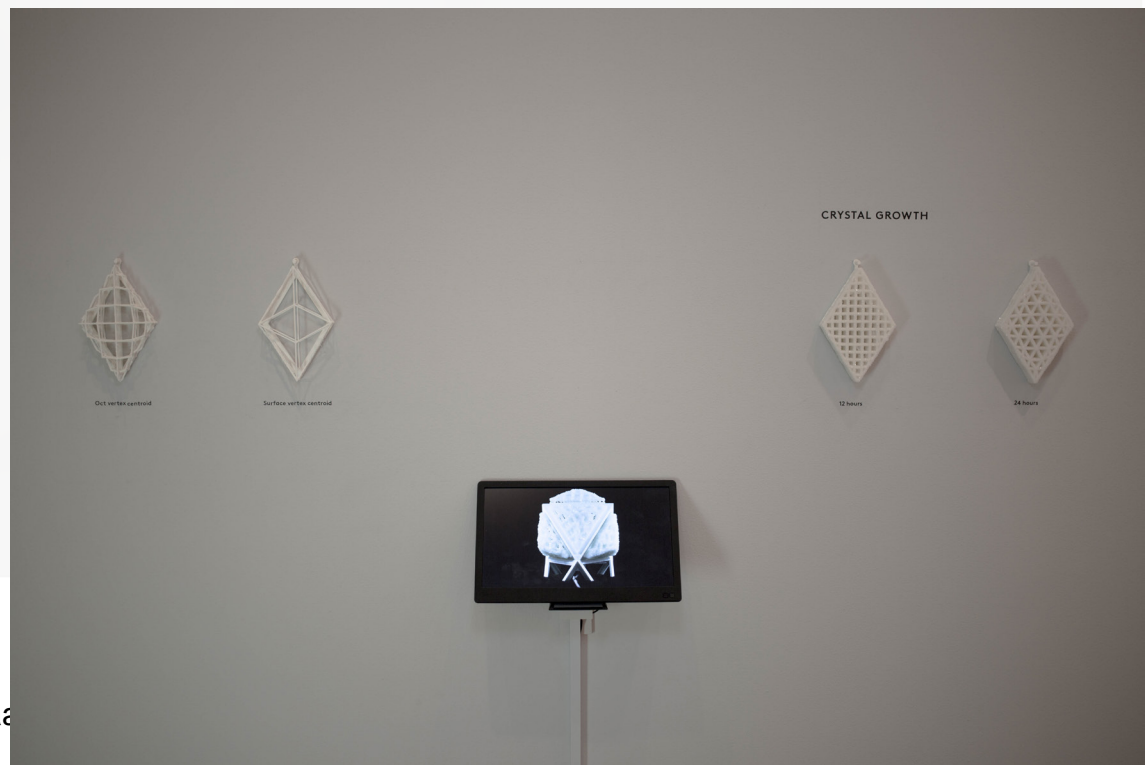
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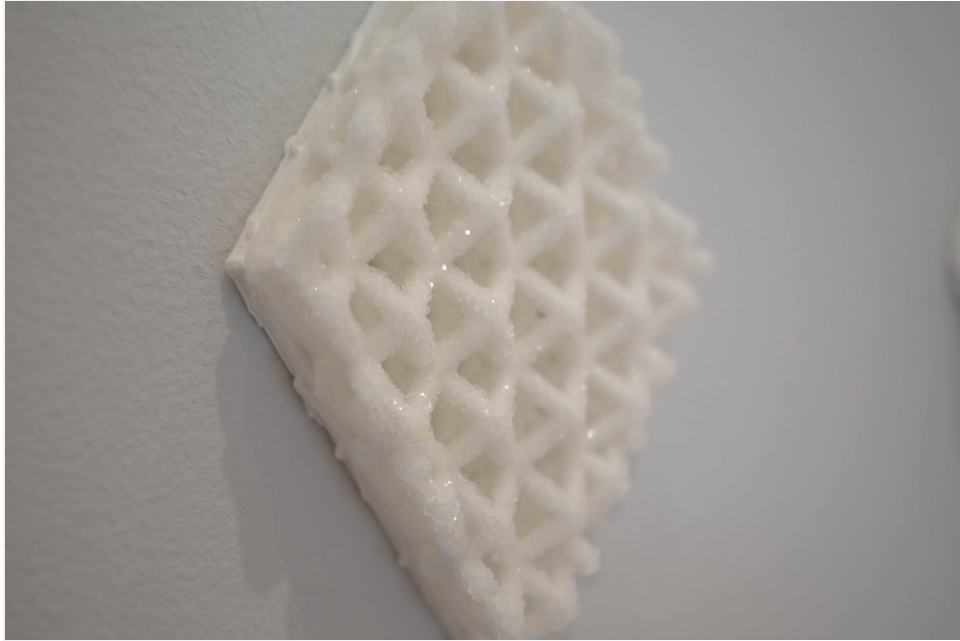
LATTICE STRUCTURES



CRYSTAL GROWTH







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BIBLIOGRAPHY

- 1 S. Jack Hu, "Evolving Paradigms of Manufacturing: From Mass Production to Mass Customization and Personalization," *Procedia CIRP*, Forty Sixth CIRP Conference on Manufacturing Systems 2013, 7 (January 1, 2013): 3-8, <https://doi.org/10.1016/j.procir.2013.05.002>.
- 2 Hu.
- 3 Hu.
- 4 Neri Oxman et al., "Material Ecology," *Computer-Aided Design, Material Ecology*, 60 (March 1, 2015): 1-2, <https://doi.org/10.1016/j.cad.2014.05.009>.
- 5 P. Young, G. Byrne, and M. Cotterell, "Manufacturing and the Environment," *The International Journal of Advanced Manufacturing Technology* 13, no. 7 (July 1, 1997): 488-93, <https://doi.org/10.1007/BF01624609>.
- 6 Elodie. Ternaux, *Industry of Nature: Another Approach to Ecology* (Amsterdam, Netherlands : Minneapolis, MN: Frame Publishers ; Trade distribution, USA and Canada, Consortium Book Sales & Distribution, 2012).
- 7 Elodie. Ternaux.
- 8 Elodie. Ternaux.
- 9 "99% Invisible," 99% Invisible, October 15, 2018, <https://99percentinvisible.org/>.
- 10 Elena Lurie-Luke, "Product and Technology Innovation: What Can Biomimicry Inspire?," *Biotechnology Advances* 32, no. 8 (2014): 1494-1505, <https://doi.org/10.1016/j.biotechadv.2014.10.002>.
- 11 "Person Overview < Neri Oxman," MIT Media Lab, October 15, 2018, <https://www.media.mit.edu/people/neri/overview/>.
- 12 Oxman et al., "Material Ecology."
- 13 "Person Overview < Neri Oxman."
- 14 Matt Pearson, *Generative Art: A Practical Guide Using Processing* (Place of publication not identified Manning, 2011).
- 15 DevicePlus Editorial Team2, "Robotics and 3D Printing: Ushering in the 4th Industrial Revolution," *Device Plus* (blog), December 6, 2017, <https://www.deviceplus.com/connect/robotics-3d-printing/>.
- 16 "Five Million Jobs by 2020: The Real Challenge of the Fourth Industrial Revolution," *World Economic Forum*, October 23, 2018, <https://www.weforum.org/press/2016/01/five-million-jobs-by-2020-the-real-challenge-of-the-fourth-industrial-revolution/>.
- 17 Joan Horvath, "A Brief History of 3D Printing," in *Mastering 3D Printing* (Apress, 2014), <http://proquest.safaribooksonline.com/book/hardware/3d-printing/9781484200254/chapter-1-a-brief-history-of-3d-printing/sect1.html>.
- 18 "About | Emerging Objects," accessed April 15, 2019, <https://www.emergingobjects.com/about/>.
- 19 "Saltygloo | Emerging Objects," accessed November 24, 2018, <http://www.emergingobjects.com/project/saltygloo/>.
- 20 "Erez Nevi Pana Designs 'Guilt-Free' Vegan Furniture Using Salt and Soil," *Dezeen*, April 18, 2018, <https://www.dezeen.com/2018/04/18/erez-nevi-pana-vegan-furniture-milan-design-week/>.
- 21 "Erez Nevi Pana Designs 'Guilt-Free' Vegan Furniture Using Salt and Soil," *Dezeen*, April 18, 2018, <https://www.dezeen.com/2018/04/18/erez-nevi-pana-vegan-furniture-milan-design-week/>.
- 22 "The Solar Sinter by Markus Kayser," *Dezeen*, June 28, 2011, <https://www.dezeen.com/2011/06/28/the-solar-sinter-by-markus-kayser/>.

23 "The Solar Sinter by Markus Kayser:"

24 "Project Overview < Silk Pavilion," MIT Media Lab, accessed November 24, 2018, <https://www.media.mit.edu/projects/silk-pavilion/overview/>.

25 "Project Overview < Silk Pavilion," MIT Media Lab, accessed April 15, 2019, <https://www.media.mit.edu/projects/silk-pavilion/overview/>.

26 "Front Page," Full Grown, accessed April 15, 2019, <https://fullgrown.co.uk/>.

27 "Front Page:"

28 "How Do Desert Roses Form?," accessed April 15, 2019, <http://www.geologyin.com/2017/06/how-do-desert-roses-form.html>.

29 "Crystallization - an Overview | ScienceDirect Topics," accessed April 15, 2019, <https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/crystallization>.

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