


MATERIAL ACTS

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Experimentation in Architecture and Design

CONTENTS

Foreword

Over the past six decades, Craft Contemporary has produced programs that reveal craft as not merely a pastime but a profound medium through which we can educate, captivate, provoke, and empower. The museum has consistently championed the transformative power of artmaking, revealing its potential to touch lives in unexpected and deeply meaningful ways. Since its earliest days, Craft Contemporary has evolved yet remained true to its core mission to offer a sanctuary for those seeking to explore their creativity. It has provided countless individuals with the tools and space to express themselves, find solace, and connect with others through the shared experience of making.

In a world where technology often dominates attention, the importance of handmade art cannot be overstated. Art is not just a medium of expression; it is a powerful tool that can improve emotional and social well-being. When we engage with and appreciate handmade art, we participate in an ancient and profoundly communal tradition. In Los Angeles County, a region marked by its diverse population and wide-ranging socio-economic disparities, Craft Contemporary offers inclusive educational programs designed to bridge gaps, bringing the transformative power of art to underserved publics. Through workshops, exhibitions, and community programs, Craft Contemporary has opened its doors to people of all ages and backgrounds to lead an art-full life. It has become a place where stories are told, traditions are honored, and new ideas are born. Here, art is not confined to the walls of the museum but spills out into the community, enriching the lives of those who engage with it.

As we approach our 60th anniversary since our founding by Edith Wyle, we look forward with gratitude and hope, knowing that Craft Contemporary will continue to inspire and connect. As we embark on our next chapter, our commitment to sustainability is integral to our vision. The Craft Contemporary team is working on a climate policy to be implemented museum-wide, focusing on improving working practices related to environmental issues that disproportionately affect underserved and under-resourced communities especially here in Los Angeles. We will strive to create zero-waste exhibitions and to have a positive and forward-thinking impact on the environment.

Material Acts: Experimentation in Architecture and Design is a testament to Craft Contemporary's commitment to sustainability and innovation and is our contribution to the Getty Foundation's PST ART: Art & Science Collide, an exemplary initiative of aligned programs in museums and art institutions across Southern California. This landmark exhibition navigates the intricate relationships between nature, technology, and human ingenuity, illuminating the forefront of material exploration in the domains of architecture, craft, and science. The exhibition explores how artists and designers are responding to environmental challenges by rethinking material production and processes, revealing the entanglements of craft and design with our planet's future. *Material Acts* not only showcases groundbreaking work but also aligns with our institutional goals of promoting environmental awareness and responsibility.

Reflecting on my first year as Executive Director, I am reminded of my beginnings as a curatorial assistant during the first PST initiative, Pacific Standard Time: Art in L.A. 1945–1980, which profoundly influenced my career path. It is an honor to now lead Craft Contemporary in contributing to PST ART: Art & Science Collide. I have the privilege of extending my sincere gratitude to the Getty Foundation and its bold leadership, and the PST ART team—Joan Weinstein, Heather MacDonald, Katie Underwood, Zachary Kaplan, and Allison Hernandez.

Special appreciation goes to co-curators Kate Yeh Chiu and Jia Yi Gu for their vision and stewardship, as well as to Strat Coffman, Hilary Huckins-Weidner, Kate Rouhandeh, Becca Lofchie, the exhibition design team of Spinagu and yyyy-mm-dd with assistance from Esin Karaosman, and the many contributors to *Material Acts*.

I would like to especially thank my predecessor, Suzanne Isken, for organizing and initiating this exhibition.

My heartfelt gratitude also goes to the dedicated Craft Contemporary Board of Trustees and staff, past, present, and emerging: Frida Cano, Joseph A. Baca, Adrianne Toomey, Andres Payan Estrada, Kate Zankowicz, Danila Cervantes, Sherry Chen, Erika Kieffer, Hana van der Steur, Melinda Wax, Vicente Puga, Albert Huezo, Jules Kresnicka, Alex Gonzalez-Garcia, Chris Marshall, Holly Jerger, Billie Rae Vinson, Prima Jalichandra-Sakuntabhai, and the many skilled hands in our preparatory team. Your passion and commitment to our communities are exemplary.

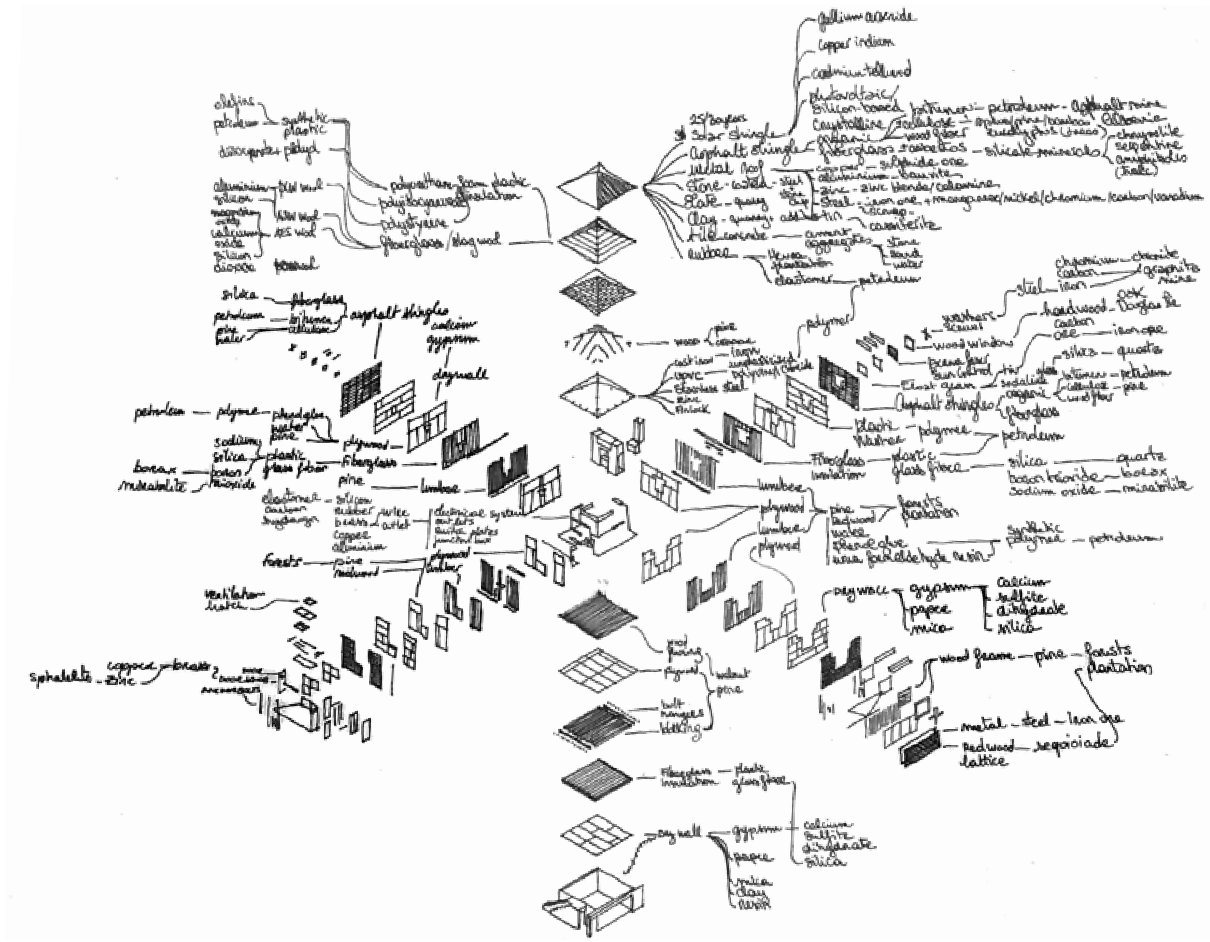
As you explore this catalog and exhibition, I invite you to ponder the profound implications of our material culture and to envision a future where nature, craft, and technology harmonize in sustainable coexistence.

—Rody N. Lopez
Executive Director
Craft Contemporary

Verbing with Materials

Kate Yeh Chiu
and
Jia Yi Gu

Material Acts: Experimentation in Architecture and Design—comprising both this book and an exhibition of the same name—begins with a reframing of materials as processes. Materials are typically described as raw resources, fixed products, or inert objects to be sourced from a shelf in the store—a function of commodity more than of making. Yet, such understandings of materials belie the complex logistical, economic, ecological, and technological actions that transform matter into the material substrate for our lives. Instead, *Material Acts* considers materials as participants in and outputs of cultural practices and techniques. Prior to their arrival at a building site, materials are selected, treated, and redefined by processes conducted by human hands and machines (the latter of which can be understood as an extension of the human hand) across various locations. Consider the simplest dimensional lumber found at the hardware store: it has been harvested, milled and sawn, pressure-treated, decontaminated, and transported. Concrete, similarly, can be understood as a series of logistical operations and energy flows—the result of a vast geography of extractive activities, uneven labor practices, complex managerial coordination, and carbon dioxide emissions. Even after a building



Charlotte Malterre-Barthes, *Scales of Extraction after Morphosis*, 2021. Annotation to Morphosis's exploded diagram of 2-4-6-8 House tracing the provenance of materials by linking building elements back to sites of extraction and industry. Courtesy of Charlotte Malterre-Barthes.

is complete, the materials found within it embody potential for alteration, continuing an unending cycle of change. This perspective of materials as an ongoing process—rather than as raw resources or finished products—centers human actors and systems in the event of the material transformation, reminding us that materials are not inert objects, but active.

In *Material Acts*, five gerunds operate as cultural techniques in material production: *Animating, Disassembling, Feeding, Re-fusing*, and *Stitching*. Whether through the human arrangement of sensors, the configuration of thermobimetals, or the calculation of humidity in wood, practices that engage with techniques of *Animating* redesign materials to perform actions found in or approximate to living systems. (Animating: An Introduction, 18) In *Feeding*, design experiments harness the metabolic activities of living organisms (such as cells, bacteria, yeast, algae, and mycelia) to produce skins, structures, and architectural components. (Feeding: An Introduction, 80) Acts of *Disassembling* experiment with how buildings come apart, working through notions of obsolescence, dismantlement, and material reuse. (Disassembling: An Introduction, 46) *Re-fusing* gathers design practices that respond to our current environmental crises but by rejecting standardized conventions and by testing alternate material collection and solidification methods with a focus on place. (Re-fusing: An Introduction, 110) *Stitching* presents contemporary work situated at the confluence of distinct communities of knowing, gathered from different disciplines and geographies—bridging, with a stitch, not only materials but also cultures of knowledge. (Stitching: An Introduction, 148)

Materials are presented as verbs in lieu of fixed objects, as authored rather than discovered conditions. Instead of approaching material experimentation through a narrative of "newness," this curatorial framework asks how materials change, through what operations, and to enable what actions. What does it mean to fire a building? (Fired-on-site Masonry, 214) To feed a SCOBY? (Bacterial Cellulose Sheets, 206) To print biopolymers? (Biogel Sheets, 200) To source locally? (Bioregional Building Products, 218) And to recirculate waste? (Waste Plastic Cladding, 216) How are materials technologically constituted? In *Material Acts*, the term technology does not just encompass an inventory of digital scanners, precision instruments, and 6-axis robots engaged in the processes of a material's making; it also includes the activities that engage humans with these objects: operations and procedures that link one step to the next. A focus on technologies and techniques offers a lens onto agents and actors, through which materials are viewed not as novelties but as ongoing events.

An exhibition and publication on material experimentation in this era of climate crisis invites reflection on relationships with nature. Making materials, as Pamela Smith reminds us, constitutes a craft and scientific mode of knowing nature, requiring embodied interactions and the development of material logics.[1] However, *Material Acts* does not operate with a singular definition of "nature" nor any particular associated cultural value. Instead, the project explores how nature stands in as an elusive concept and unstable category for designers working on material experimentation. Historian of science Lorraine Daston has described the tendency to ascribe values to nature as a "naturalistic fallacy—a kind of covert smuggling operation in which cultural values are transferred to nature, and nature's authority is then called upon to buttress those very same values."[2] Architecture has similarly borrowed many of these arguments to theorize and materialize its own discourse in relation to ideas of nature—to tame nature (by providing shelter), emulate nature (through ornament), or embody nature and its processes (biomimicry). The research presented in *Material Acts* leans away from "nature" as a romantic origin or as authority. While nature has often stood in as a model, metaphor, or resource, recent global upheavals in ecology and technology are driving intensified understandings of nature's tangible and imagined substrate. For example, in incorporating living systems, metabolic nature is converted into an infrastructure for production. (Feeding, 78) Designing responsiveness into inert materials introduces a notion of animacy and a "nature" to materials. (Animating, 16) In bioregional design practices, where material are sourced locally, material inventories begin to mirror notions of closed ecological systems. (Re-fusing, 108) *Material Acts* explores how a multitude of *natures* alongside cultural values enter into material processes and practices, showcasing how contemporary artists, designers, and architects mobilize, confound, and generate natures through the *making* of material.

In verbing with materials, questions of site come to the fore. Materials are necessarily site-specific and highly mediated through networked geographies. As materials pass from one state of matter to another, they also cross through multiple production sites. Often, the site of material research and experimentation is imagined as a sterile, industrial setting, where materials may be experimented upon in supposed isolation; on the lab bench, elements may be isolated, scaled, controlled, and manipulated in ways imagined to be unmanageable in other environments. This laboratory life alludes to working factories where certain ideas about productivity, authorship, determinism, and material "progress" persist. To find experiments that seek to challenge our material habits and envision a different future, *Material Acts* looked to the peripheries of industry, beyond manufacturing and global supply

1 See the book *Ways of Making and Knowing*, edited by Pamela H. Smith with Amy R.W. Meyers and Harold J. Cook (New York: Bard Graduate Center, 2017).

2 Lorraine Daston, *Against Nature*, (Cambridge, MA: The MIT Press, 2019), 4.

chains, toward spaces like the artist studio (The Studio, 20), the school (The Classroom Laboratory, 48), the farm (The Farm and Factory, 82), the wilderness (The Seashore, 150), and the yard (The Yard, 112). How do materials register not just labor but place? How do procedures relate to the environment, and where do models of experimentation take place?

Material productions also represent histories and concepts of making that span disciplines. While craft, art, and architecture often employ materials techniques, the notion that the making of and experimentation with materials embody cultural techniques is an underexplored idea.[3] In the spectrum of material research and techniques considered by *Material Acts*, knowledge and know-how move freely between often siloed cultures. Transdisciplinary and even anti-disciplinary approaches spotlight convergences of differently classified forms of labor, such as the introduction of dreadlocking techniques to machine knitting (Knit Dreadlocks, 226), the integration of hand-assisted weaving with mechanized material extrusion (Fiber-rich Earthen Textile, 228), and the facilitation of non-human life and death upon 3D-printed forms (Algae-laden Hydrogels, 210) (Biocalcified Paper Foam, 208). Systems of making and knowing that emerge are sustained by human communities reliant on mediation, often in the form of what Bruno Latour calls "inscriptions," or documents defined by a "know-show" function, per Lisa Gitelman.[4] These documents include diagrammatic correspondences (How to Unlog, 76), conference proceedings (How to Cut Cookies, 74), algorithmic programming (How to Tie Wood, 40), and templates and molds (How to Stretch, 42)—offering opportunities for circulation, reproduction, and the adaptation of processes by collaborators and peers.

Within this framework that considers materials as extended events encompassing participants, processes, and myriad consequences, *Material Acts* acknowledges that a multitude of positions toward materials expands beyond what can be captured in one exhibition and book, let alone five non-mutually exclusive material acts. To this effect, this publication operates not as a catalogue for the exhibition but, more critically, as an extension and prompt for further thought. Interlocutors Didem Ekici, Caroline A. Jones, and Ben Loescher join conversations to offer respectively historical, scholarly, and practical perspectives. (Stitching Conversation, 176) (Feeding Conversation, 100) (Re-fusing Conversation, 136) Contributors' essays offer surveys, critical analysis, and extra-disciplinary attitudes toward material actions. How might material "performance" be understood when considering responsiveness and animacy in matter? (Jennifer Johung, 34) How is the human disciplining of phenomena—for example, control of combustion and heat—implicated in our interactions with material? (Mae-Ling Lokko, 124) How do we engage living matter as both commodity and cohabitant? (Amy Zhang, 94) How do material acts engage degrowth and care movements, and what values do they offer in response to or as alternatives to the intense degradation of our built environment and the climate crisis at our doorstep? (Elsa MH Mäki, 164) (Zofia Trafas White, 62) These questions elucidate and broaden concerns put forth by *Material Acts* and gesture toward the opening up of this project.

Material Acts: Experimentation in Architecture and Design is a study of how material knowledge is enacted, how natures are generated, and how matter makes matter. As Donna J. Haraway writes in *Staying with the Trouble: Making Kin in the Chthulucene*, "It matters what matters we use to think other matters with; it matters what stories we tell to tell other stories with; it matters what knots knot knots, what thoughts think thoughts, what descriptions describe descriptions, what ties tie ties. It matters what stories make worlds, what worlds make stories." Consider this publication a set of field notes that ties recent material research and experimentation to urgent questions around the design of systems, procedures, and ideas. The output of material research is not merely a product—it is a set of operations, a flow of energy, a redefinition of the animal, a displacement of labor (in relationship to the tool or of time), a reorientation of the hand, a material fact for the future, and a suggestion for ecological repair.

3 Two consecutive Venice Biennale presentations, *American Framing* (2021) and *Everlasting Plastics* (2023), have focused on the prevalence of wood and plastics as commodities in the American landscape. The 2017 symposium and publication *Being Material* presents materials adjectives such as "programmable," "wearable," and "invisible," an approach to materials that reinforces object over action. See Marie-Pier Boucher, Stefan Helmreich, Leila W Kinney, Skylar Tibbits, Rebecca Uchill, Evan Ziporyn, eds. *Being Material* (Cambridge, MA: The MIT Press, 2019).

4 On the role of documents and inscriptions in scientific knowledge reproduction, see Bruno Latour and Steve Woolgar, *Laboratory Life: The Construction of Scientific Facts* (Princeton, NJ: Princeton University Press, 1986). On the "know-show" function of document forms, see Lisa Gitelman, *Paper Knowledge: Toward a Media History of Documents* (Durham, NC: Duke University Press, 2014).

Animating

Animating: An Introduction

Materials are commonly assumed to be inert, yet architectural thought has, at times, yielded to a suspicion that materials carry intrinsic natures or properties.[1] When Louis Kahn asked, "What do you want, Brick?" he crystallized a long-standing architectural intuition that materials harbor agency. The brick wants to be an arch, not a lintel. By psychologizing the desires of a building component such as brick (and transforming a question into an aphorism), the architect indirectly granted a will, selfhood, and "nature" to inanimate matter. While contemporary designers have moved away from the notion that a brick might encompass desire, a deep interest in materials' capacity to self-actualize and self-animate continues to drive design research. *Animating* presents design practices that embed responsive materials within assemblies, working through notions of animacy, responsiveness, and spontaneity in architecture.

Acts in *Animating* infuse movement and "liveness" into inert materials. Whether through the human arrangement of sensors, the configuration of thermal bimetals, or the calculation of humidity in wood, practices that engage with techniques of *Animating* redesign inert materials to perform actions found in or approximate to living systems. Designers arrange materials to respond to environmental cues such as temperature, carbon intake, and humidity, to generate changes to surface porosity, visual transparency, and/or structural composition.

In some cases, transformation is induced through physical-chemical responses activated by changing temperature. For Doris Sung's installation *Bloom*, her studio assembled over 14,000 pieces of thermobimetal into ocular shapes that curl and expand in response to heat, allowing the architecture to "breathe" within heated environments. Responsive Bimetal, 186 The study models, test sheets, and prototypes accrued in Sung's studio are evidence of her experimentation and iterative process exploring material cuts, shape, and texture. The Studio, 20

In other cases, the practice of animating materials requires designing a choreographed sequence of inputs and outputs that echo a homeostatic model of nature. Omar Khan's deployment of elastomers in *Open Columns* results in flexible columnar forms that drop when carbon dioxide levels increase, measuring invisible environmental cues such as carbon in the air. Actuated Elastomers, 188 Here, material responsiveness is induced electro-mechanically—sensors gather environmental data and initiate actuators to activate changes to the physical configuration. Dylan Wood's research in self-shaping wood relies on the desiccation of wood to induce structural and formal

performance. Hygromorphic Wood, 190 The self-shaping process begins with the evaporation of water from wood, transforming fluid embedded in wood grain to a gaseous state in surrounding air. In many of these projects, movement in self-actuated materials (i.e., materials designed to activate, move, or regulate themselves) are read as a sign of responsiveness.

In contrast with acts of *Feeding*, where the labor of living organisms is conducted to produce matter, practices in *Animating* direct inert matter to perform seemingly autonomous functions. Feeding: An Introduction, 80 What does it mean to induce materials with animacy or "liveness"?[2] What does it mean to assign a notion of the self to material? What does it mean to build interrelationships between materials or architectural configurations and environmental cues, be it heat, CO_2, or H_2O? In a way, animating material re-configures the designer as a nurturing force in a material's self-realization—an invisible hand or maternal figure that coaxes materials into being.

What might animacy offer us beyond automation? Jennifer Johung expands on this question through an examination of the work of artist Guy Ben-Ary. Jennifer Johung, 34 Working with an interdisciplinary team of art and science collaborators, Ben-Ary constructed an interaction between neural cells from the late composer Alvin Lucier and a grid of electrodes that records the neurons' electrical signals. The process designs a reassembly of biological matter, electrical signals, and sound frequencies from Lucier's brain cells. Johung's essay invites us to relocate design (or animacy through design) not in the assembly of final forms, but in terms of performance and eventhood—between living and nonliving human subjects, neural signals, and exterior inputs proposing to be music and performance. In this context, animacy acutely shifts away from life itself, instead extracting processes of "liveness," spontaneity, and responsiveness from matter, extending the way we understand and appreciate the performative properties of seemingly inert materials in architecture.

1 The idea that inert materials carry intrinsic properties also circulated in early architectural theories of style by Gottfried Semper, Adolf Loos's theories of ornament and morality, and were forwarded by modernist architects in pursuit of a rational organization of matter into building. Le Corbusier's five point litany on the new spirit of architecture was constructed on a proclaimed "truth" to material, as fundamental and intrinsic as color, weight, and size.

2 For a history of animacy in mechanical assemblages, see Jessica Riskin, *The Restless Clock: A History of the Centuries-Long Argument over What Makes Living Things Tick* (University of Chicago Press, 2016).

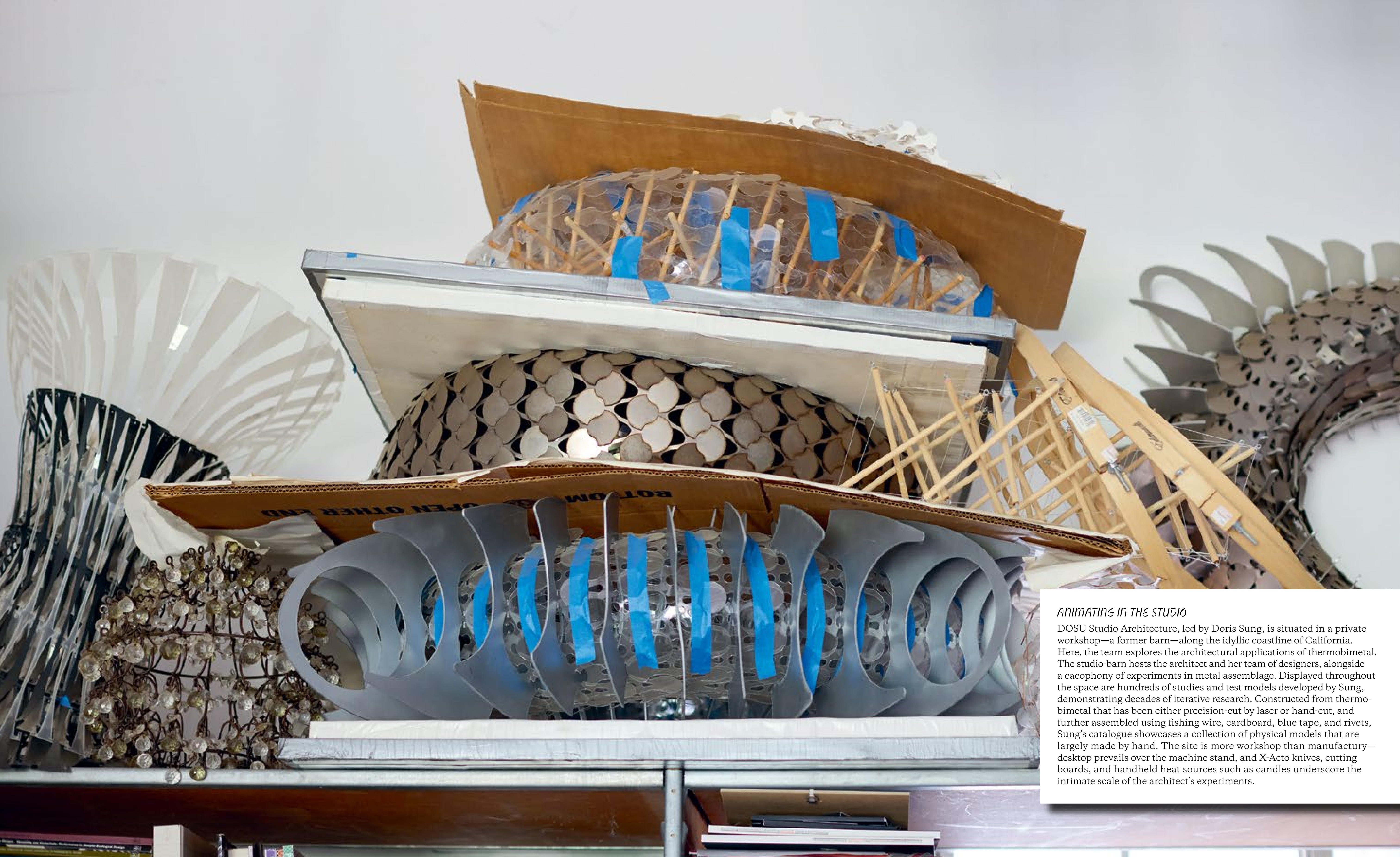
The Studio

DOSU Studio Architecture
Los Angeles, CA, USA

Responsive Bimetal, 186

Photography by Ye Rin Mok





Animating in the Studio

DOSU Studio Architecture, led by Doris Sung, is situated in a private workshop—a former barn—along the idyllic coastline of California. Here, the team explores the architectural applications of thermobimetal. The studio-barn hosts the architect and her team of designers, alongside a cacophony of experiments in metal assemblage. Displayed throughout the space are hundreds of studies and test models developed by Sung, demonstrating decades of iterative research. Constructed from thermobimetal that has been either precision-cut by laser or hand-cut, and further assembled using fishing wire, cardboard, blue tape, and rivets, Sung's catalogue showcases a collection of physical models that are largely made by hand. The site is more workshop than manufactory—desktop prevails over the machine stand, and X-Acto knives, cutting boards, and handheld heat sources such as candles underscore the intimate scale of the architect's experiments.

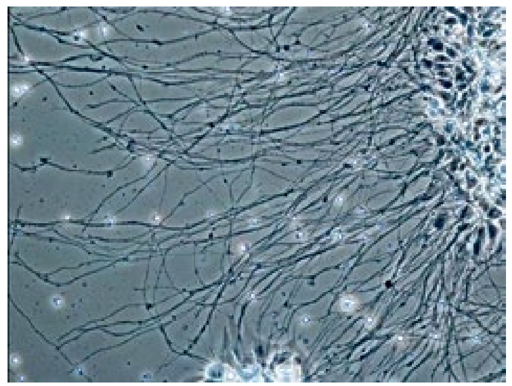
Animating: Material Agency, Performance, and Intelligence

Jennifer Johung

To animate means, among other things, to give life to inert objects.[1] As contemporary biology moves steadily away from determining the underlying laws that define life to instead consider an open field of generative, dynamic collaborations that enliven organic matter, a new theory of materialism has emerged across the disciplines of political science, philosophy, and geography. New materialism proposes that all matter has agency akin to living humans. According to political theorist and philosopher Jane Bennett, this understanding of matter acknowledges "the capacity of things—edibles, commodities, storms, metals—not only to impede or block the will and designs of humans but also to act as quasi agents or forces with trajectories, propensities, or tendencies of their own."[2] From the components of an electrical grid, to the food that living beings consume and through which they are transformed, to the irregular crystalline structure that allows iron to turn into steel when heated, these often-dissonant assemblages of matter act together to impact our human designs for and situation in the world.[3]

Without stable distinctions between the force of animate and inanimate matter within such assemblages, the act of giving life can be understood to occur through material encounters and possible exchanges between all forms, structures, and systems, both living and nonliving. For Bennett, this transition "from a world of nature versus culture to a heterogeneous monism of vibrant bodies" recognizes that organic and inorganic material cannot be held so far apart from each other, cannot be completely fixed, bounded, or contained: all are energetic tendencies that transform by way of each other.[4] The quantum physicist and feminist theorist Karen Barad affirms the entanglement of materiality, noting that "independent objects are abstract notions."[5] Instead, objects emerge through their relationships with other things, rather than existing prior to them. These relationships momentarily sediment matter into objects, yet also offer the possibility of reconfiguring those forms across time through material processes of exchange where one thing can become another.

Alongside a new materialist conception of agentic matter, performance theory brings embodied context and duration to the formation of things in space, and calls attention to the larger environmental and temporal conditions that make any object, interaction, or exchange possible. As such, in tandem with the give and take of vibrant assemblages that make up each form, dynamic specificities such as ground, climate, atmosphere, and the particularities of our bodies enliven and are enlivened by encounters occurring in real time and situated



cellF, Ben-Ary's stem cells differentiated from neurons on day eight of the process, SymbioticA labs, University of Washington. Photo: Guy Ben-Ary. Courtesy of Ben-Ary.

1 *Merriam Webster*, "Animate (transitive verb), 2a." https://www.merriam-webster.com/dictionary/animate#dictionary-entry-2.

2 Jane Bennett, *Vibrant Matter: A Political Ecology of Things* (Durham, NC: Duke University Press, 2010), viii. See also: Diana Coole and Samantha Frost, "Introducing the New Materialism," in *New Materialisms: Ontology, Agency, and Politics*, eds. Coole and Frost (Durham, NC: Duke University Press, 2010).

3 For more on electricity, food, and metals, see Bennett, 25, 39, 59.

4 Bennett, 121. Mel Y. Chen also considers "how matter that is considered insensate, immobile, deathly, or otherwise 'wrong' animates cultural life in important ways" in Mel Y. Chen, *Animacies: Biopolitics, Racial Mattering, and Queer Affect* (Durham, NC: Duke University Press, 2012), 2.

5 Karen Barad, "Matter feels, converses, suffers, desires, yearns, and remembers: Interview with Karen Barad," *New Materialisms: Interviews and Cartographies*, ed. Rich Dolphijn and Iris van der Tuin (Ann Arbor, MI: Open Humanities Press, 2012), 61. See also: Karen Barad, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning* (Durham, NC: Duke University Press, 2007).

in a particular site. Within performance theory, the differentiation between performance and performativity is key to understanding the ways in which forms are iterated and sustained across time, as well as the moments and sites in which transformations are possible. The philosopher J. L. Austin defined performative speech acts as statements that enact something as they are being uttered, like the "I do" of a wedding.[6] The action of joining two people together in marriage occurs through the repetition of this vow over time, and because all parties giving and receiving these words have similar expectations every time they are spoken.

At work around the repetitive framing of performativity, performance refers to the variable embodiment of these iterations, and to the number of ways that performativity's promise to enact the same thing, again and again, can and often does go wrong. This leads to the potential for revision or transformation beyond reiteration.[7] As performance theorist Peggy Phelan argues: "In moving from the grammar of words to the grammar of the body, one moves from the realm of metaphor to the realm of metonymy."[8] For Phelan, bodies perform metonymically because they can deflect and displace meaning through each unfolding of embodied action. To follow Phelan beyond the specifically human body, material objects also perform in relation to each other, resisting stable replicability and predictability. To move from the performativity of material form to its performance is to reinvest in contextual variabilities and relational dependencies across varying scales and sites towards the capacity for material change. It is to affirm the multi-directional agency of entangled matter activated between you and I, this surface and that volume, today and tomorrow.

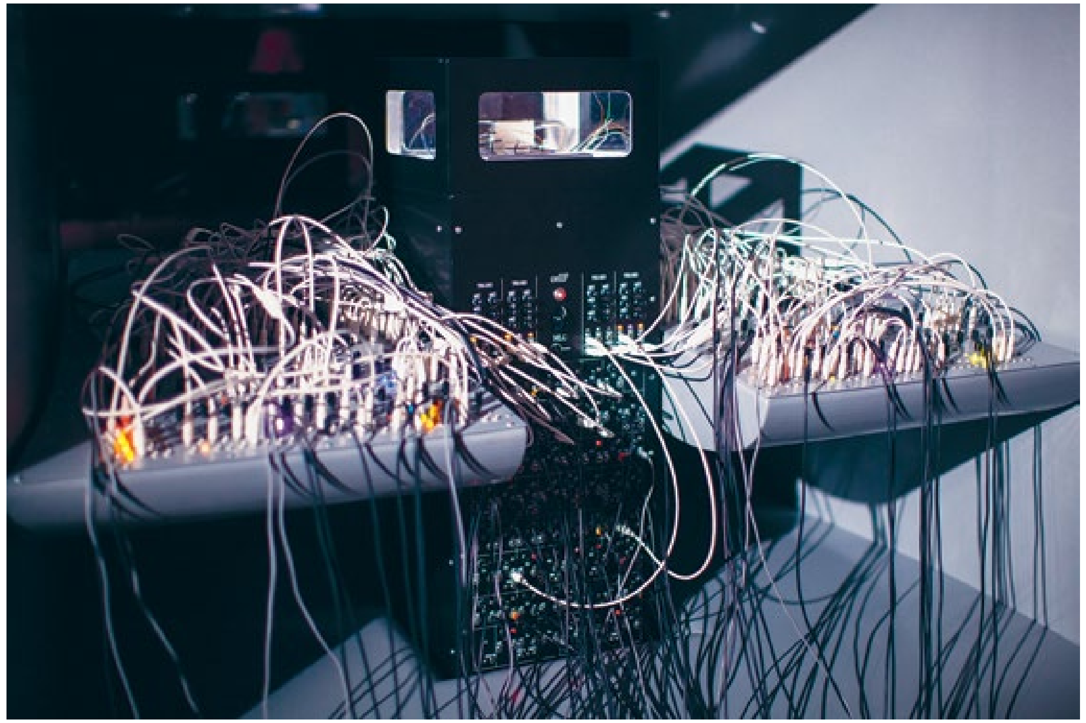
Proposing that all matter has agency, like life, not only means that matter acts and responds, but that it does so on its own, outside of any performative program that humans control with goals that we alone seek to predict. Instead, material performances that occur in the spaces, bodies, and timings of an encounter between things and beings, and that offer the capacity for transformation, also may suggest a spontaneous intelligence that is separate from ours. With their own agency, formations of matter challenge us to see beyond repetitive performative actions and expected responses, and to remain open to variable and indeterminable assemblages that change themselves and us over time, with purposes distinct from ours. These intersections of material actors decenter human plans with propositions of their own, unsettling boundaries between living and nonliving forms destabilize qualifications for intelligent life.

Artificial intelligence and its subset of machine learning proclaim to act like living humans and do more than us computationally. AI is generally performative: we feed it large quantities of data, and it sorts, filters, recombines, and refeeds it back to us.[9]

6 J. L. Austin, *How to Do Things with Words* (Cambridge, MA: Harvard University Press, 1962), 5–6.

7 For more about performative slippages, see Jacques Derrida, "Signature Event Context," *Margins of Philosophy*, trans. Alan Bass (University of Chicago Press, 1982), 307–330.

8 Peggy Phelan, *Unmarked: The Politics of Performance* (London: Routledge, 1993), 150.



cellF, neural interface and synthesizers, series of performances at the Cell Block Theatre, Sydney, 2016. Photo: Alex Davis. Courtesy of Guy Ben-Ary.

Although much faster and comprehensive than we are, as Lauren M.E. Goodland explains, "the machine 'learning' in question (in contrast to the generalizable experiential learning of humans) involves programmed instructions to update statistical weights in order to optimize predictions about specific data-driven tasks or domains."[10] While AI is built on a perceived alignment of functionality between computers and our brains, Goodland argues that it tends to ignore "more complex and situated perspectives (including the impact of physical embodiment, emotions, webs of relationality, relations of care, cultural contexts, and/or philosophical assumptions)."[11] Often negated in the promise of iterative performativity that maintains AI's feedback loop of data input and output, these multi-dimensional entanglements foreground the histories and relational conditions of material performances over time, and propose a more expansive qualification of intelligence in humans and non-humans alike.

In 2023, a group of scientists and engineers coined the term "organoid intelligence" to mark nascent research into using 3D cultures of brain cells to respond to external stimuli, starting with the premise that biological neural networks learn, adapt, and evolve in ways that artificial networks do not.[12] A decade earlier, however, the artist Guy Ben-Ary and his interdisciplinary team of collaborators were growing living brain tissue that could interact on its own with other material forms and bodies, identifying this capacity for unprogrammed decision-making as "in-vitro

9 AI can and does "hallucinate" and misfire in a parallel way to Austin's performatives. See Katherine Lee, Orhan Firat, Ashish Agarwal, Clara Fannjiang, and David Sussillo, "Hallucinations in Neural Machine Translation," https://openreview.net/pdf?id=SJxTk3vB3m.

10 Lauren M. E. Goodlad, "Editor's Introduction: Humanities in the Loop," *Critical AI* 1 (2003): 1.

11 Goodlad, 2. See also: Terrence J Sejnowski, *The Deep Learning Revolution* (Cambridge, MA: MIT Press, 2018), xi.

12 Lena Smirnova, Brian S. Caffo, David H. Gracias, et al., "Organoid intelligence (OI): the new frontier in biocomputing and intelligence-in-a-dish," *Frontiers in Science* 1 (February 28, 2023): https://www.frontiersin.org/journals/science/articles/10.3389/fsci.2023.1017235. Also, Cortical Labs in Melbourne is working on a neurobiological platform, "DishBrain," that can run very basic programs. They've already had a 2D layer of 800,000 neurons learn to play the video game Pong. See Dan Robitzski, "How Neurons in a Dish Learned to Play 'Pong,'" *The Scientist* (October 12, 2022): https://www.the-scientist.com/news-opinion/how-neurons-in-a-dish-learned-to-play-pong-70613.

intelligence."[13] In 2013, Ben-Ary sent his own skin cells to scientists at the University of Barcelona where they were reverse-engineered into human embryonic stem cells, which were then differentiated into neurons by his team in Perth.[14] Making its debut in October 2015, *cellF* is a functioning neural network that is actualized through encounters with other forms, forces, and energies. The petri dishes that host Ben-Ary's firing neurons contain a grid of electrodes that is capable of both recording the neurons' signals as well as stimulating them in a performative feedback loop. Music from live musicians is sent to the neurons as electrical stimulation, and the neurons respond through electrical impulses. Then those responses are amplified and sent to a synthesizer, creating an improvised sound assemblage that differs in each iteration and is dependent on location, timing, audience, as well as the specificities of cellular and human performers. This entangled configuration of neurons, electrodes, musicians, instruments and their combined electrical impulses and soundwaves act with and against each other, as the changing confluence of object and subject, and living and nonliving matter, in each specific environment unpredictably alters the shape and direction of every performance.

The materiality of *cellF*'s living neurons exists two-dimensionally, but it is also possible to grow three-dimensional neuronal networks ("cerebral organoids") that are structured like the intricate folded form of our brains, and thus may offer more complex and intelligent functionality over time. With 3D brains, longer-term learning, adapting, and evolving with and against external stimuli becomes possible.[15] Since 2020, Ben-Ary, Nathan Thompson, and Stuart Hodgetts have been exploring the growth of cerebral organoids from blood cells taken from minimalist composer Alvin Lucier.[16] In October 2023, two years after Lucier died, Ben-Ary, Thompson, and Andrew Fitch, along with Hodgetts and Darren Moore, premiered

Music for Surrogate Performer, The 68th International Festival of Contemporary Music, Venice Biennale, 2023. Photo: Guy Ben-Ary. Courtesy Ben-Ary.

13 *cellF* was developed by Ben-Ary in collaboration with artist Nathan Thompson, electrical engineer Andrew Fitch, scientists Stuart Hodgetts, Mike Edel and Douglas Bakkum, and musician Darren Moore. Vahri Mckenzie, Nathan John Thompson, Darren Moore, Guy Ben-Ary, "cellF: Surrogate Musicianship as a manifestation of in-vitro intelligence," *Handbook of Artificial Intelligence for Music*, ed. Eduardo Reck Miranda (Switzerland: Springer, 2021), 915–932.

14 The majority of embryonic stem cells lines have historically been cultured from surplus in-vitro fertilized embryos that will no longer be implanted into patients undergoing IVF treatments. Now we can generate pluripotency, or the capacity of stem cells to develop into any adult cell. In 2006, Shinya Yamanaka discovered that he could reprogram mouse skin cells to act like embryonic stem cells, causing those cells to revert to a prior, nascent state. Like embryonic stem cells, these "induced pluripotent stem cells" or iPS cells can self-renew and differentiate into all adult cell types. See Kazutoshi Takahashi and Shinya Yamanaka, "Induction of Pluripotent Stem Cells from Mouse Embryonic and Adult Fibroblast Cultures by Defined Factors," *Cell* 126, no. 4 (August 25, 2006): 663–676.

15 Similarly developed from reverse-engineered stem cells, organoids are very small, 3D cell cultures that structurally self-organize and differentiate into specific organ tissues. Within a rotating bioreactor that simulates gravity, these mini-organs can self-assemble up to 5-millimeters in width and to date, scientists have grown mini-brains, kidneys, lungs, intestines, stomachs, and livers. Jihoon Kim, Bon-Kyoung Koo and Juergen A. Knoblich, "Human organoids: model systems for human biology and medicine," *Nature Reviews Molecular Cell Biology* 21 (2020): 571–584. To achieve three-dimensionality as well as complex cellular development and function, scientists embed pluripotent cells in an extracellular matrix, which is the structural support that all cells have. This matrix serves as the microenvironment that supports 3D tissue growth.

16 When Lucier died in December 2021, his mini-brains were alive and his family agreed that the project should continue.

17 In similar manner to his seminal 1965 performance *Music for Solo Performer*. Alvin Lucier, "Musik för soloist/Music for Solo Performer." *Fylkingen Bulletin: International Edition. Art and Technology II* 2 (1967): 16–7. See also: Guy Ben-Ary, Nathan Thompson, Darren Moore, Andrew Fitch, *Music for Surrogate Performer* (2023), https://www.labiennale.org/en/music/2023/music-performances/guy-ben-ary-nathan-thompson-darren-moore-andrew-fitch-music-surrogate-performer.

18 Personal conversation with Ben-Ary, Thompson, and Stuart Ian Hodgetts (January 18, 2022).

19 As medical anthropologist Linda Hogle makes clear: "Human embryonic stem cells are elusive, recalcitrant entities that resist characterization and standardization" with their "distinct, cumulative identities" that change according to the specific lab environments in which they are grown. See Linda F. Hogle, "Characterizing Human Embryonic Stem Cells: Biological and Social Markers of Identity," *Medical Anthropology Quarterly* 24, no. 4 (December 2010): 433.

Music for Surrogate Performer, a performance in which Lucier's brain tissue, grown postmortem over another interface of electrodes, plays percussive instruments.[17] This assemblage of animate and inanimate materials, along with embodied and disembodied forms, exchange energy in the form of electrochemical signals measured in microvolts. The force and direction of this performance, improvised in real time without a preconceived program, is animated not by way of any embodied human or even solely by the living network of neurons suspended in time, but rather from the shifting entangled state of each material form interacting with others for around forty-five minutes. And in their next envisioned work, *Revivification*, the neuronal impulses of Lucier's 3D cerebral organoid will acoustically resonate with tuned metal plates that reverberate along the walls while viewers move within the installation space.[18] Ben-Ary aims to permanently install this project to highlight the long-term duration and capabilities of the organoid, as transformed by the metal, cells, bodies, and their vibrations and movements on site. This expanded temporality can activate the potential for brain-based intelligent learning through an ongoing performance that is continuously adapting in relation to past encounters and projecting towards future ones.

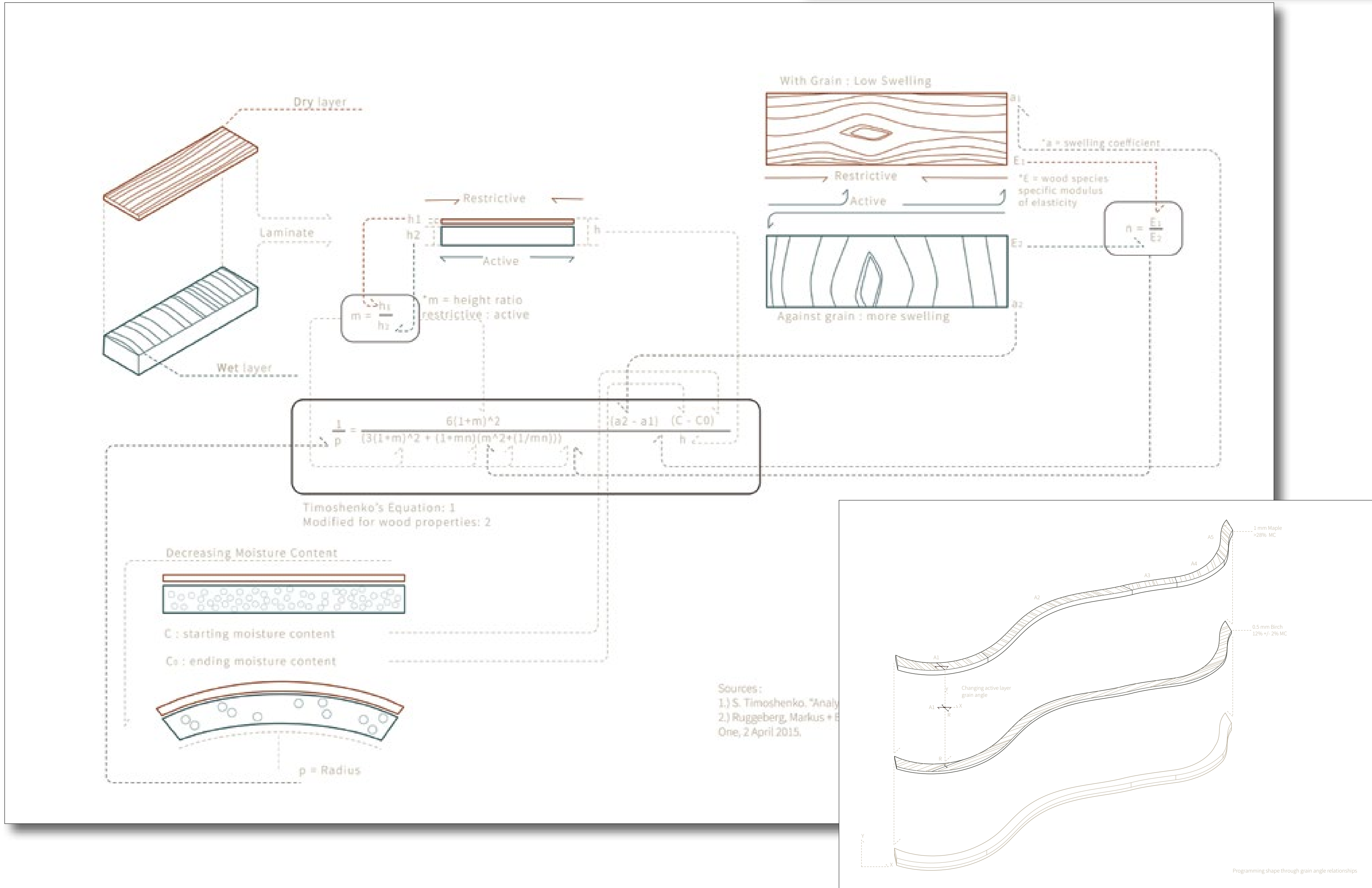
While stem cells may offer the ideal performative iteration of cellular life itself in the form of renewable life suspended out of time and context, even stem cells are haunted by their previous material existences and transformed by their actions with other beings and things in time and across various spaces.[19] This process of feedback, or the call and response of animated agentic matter, can lead towards more sustained material resonances where the effects of their interactions palpably shapeshift, as the boundaries between subjects and objects become more ambiguous and change by way of each other. Indeed, material form is animated across multiple sites of contact and moments of exchange, where the impact of heterogenous things resonating together offers the capacity for evolution over time towards unknown purposes. We can imagine this understanding of animated life in terms of sound with its seemingly intangible, immaterial, yet transformable force experienced through Ben-Ary's series of performances. But we can also consider what this means for the tangible and material ways that we seek to sediment things in the world through design. If we see all matter as agential, potentially intelligent counterparts that animate us as we animate it, we might rethink how we assemble, situate, and engage with objects and structures as our material partners. We might also see our designed forms as propositions of material convergence, rather than as conclusions, where both the possibilities and vulnerabilities of life are distributed beyond the times, scales, and sites of our living bodies.

How to Tie Wood

Ri Zarate with Dylan Wood

How do designers encapsulate material behavior within research illustration? As part of their research on self-shaping wood for a class taught by Dylan Wood, Ri Zarate developed visual diagrams and drawings to relay the movements and interactions of wood strips which self-knot as the wood dries. (Hygromorphic Wood, 190) The illustration of a knot coming into being is not merely a representation of the knot, but an inscription of its generation. This image is a visual annotation of Timoshenko's Equation, a formula which models the shearing and bending outcome of beams, adapted for wood propertes in Zarate's research. Architectural drawing and scientific writing collide in this technical document, where the architectural conventions of callouts (elements of a drawing which give detailed views of a building) inform and illustrate the abstract symbols of the formula.

Knots
Ri Zarate with Dylan Wood, *Self-Knotting Wood*, 2023. Diagrams of Zarate's research into self-shaping wood behavior utilizing the Timoshenko formula. Courtesy of Dylan Wood and Ri Zarate.

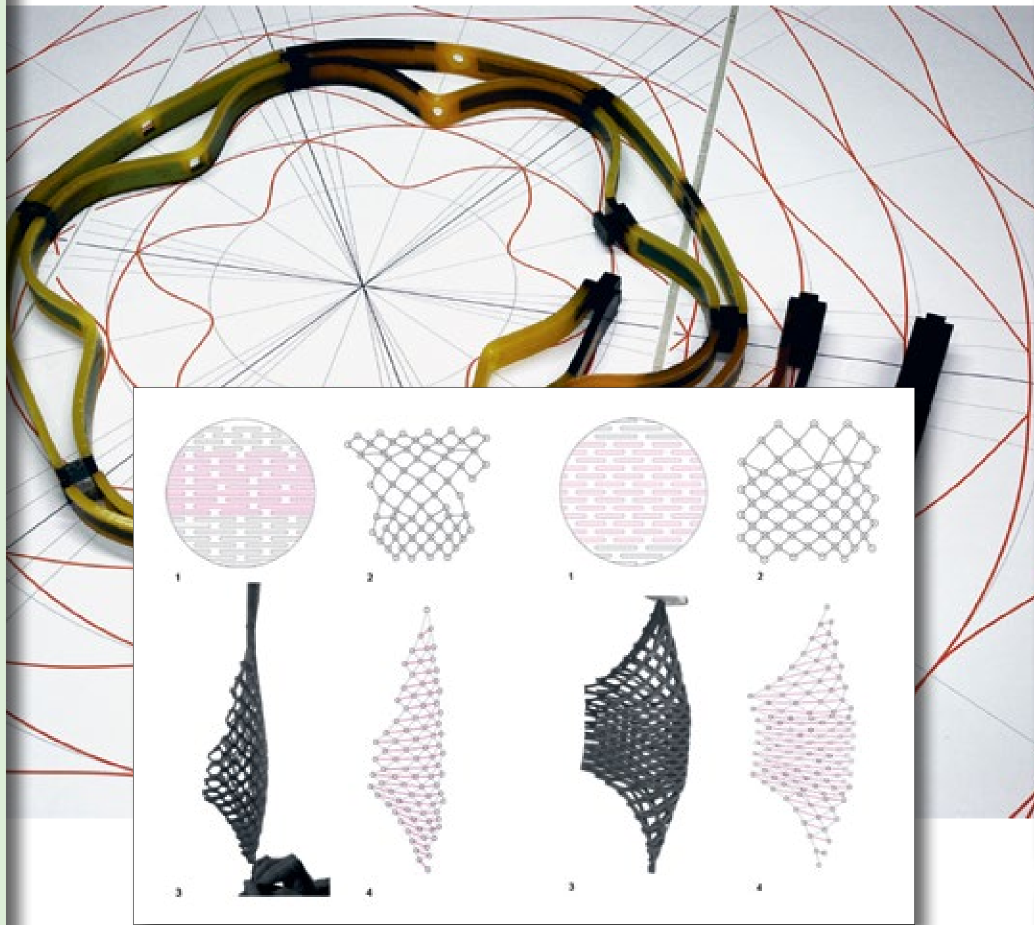


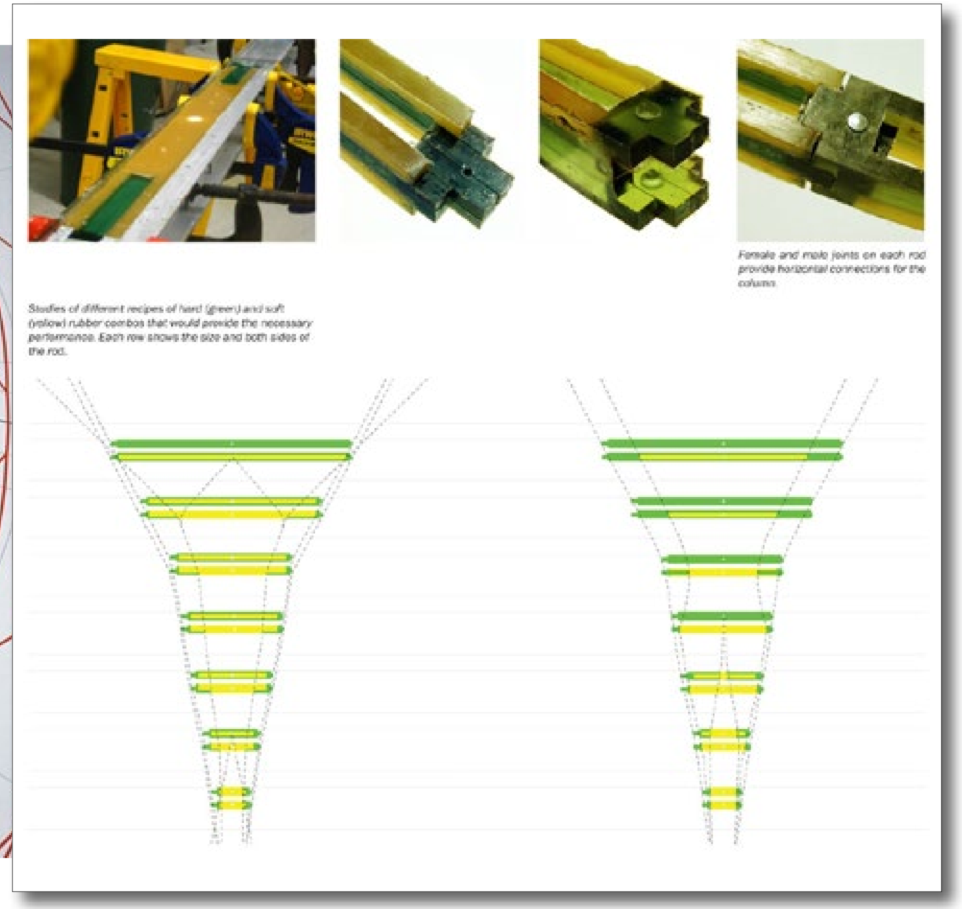
How to Stretch

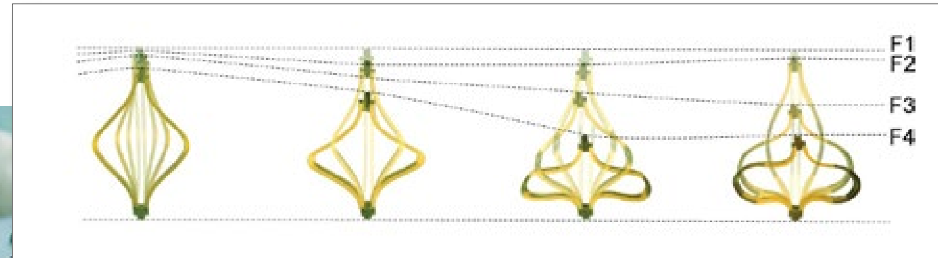
Omar Khan

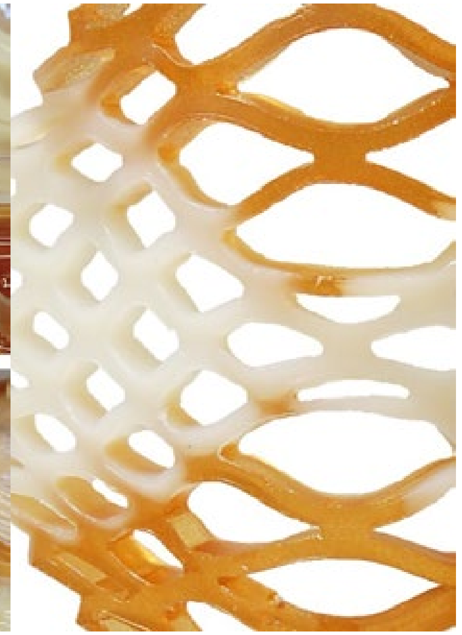
Omar Khan uses instructional laboratory posters and custom molds to provide precise procedural guidelines to facilitate the fabrication of elastomers by research assistants. (Actuated Elastomers, 188) The guides facilitate a team of fabricators in the pouring and assembling of elasomer parts for his project. Posters and templates are printed at 1:1 scale so that project parts may be directly referenced against their instructions as they are being made.

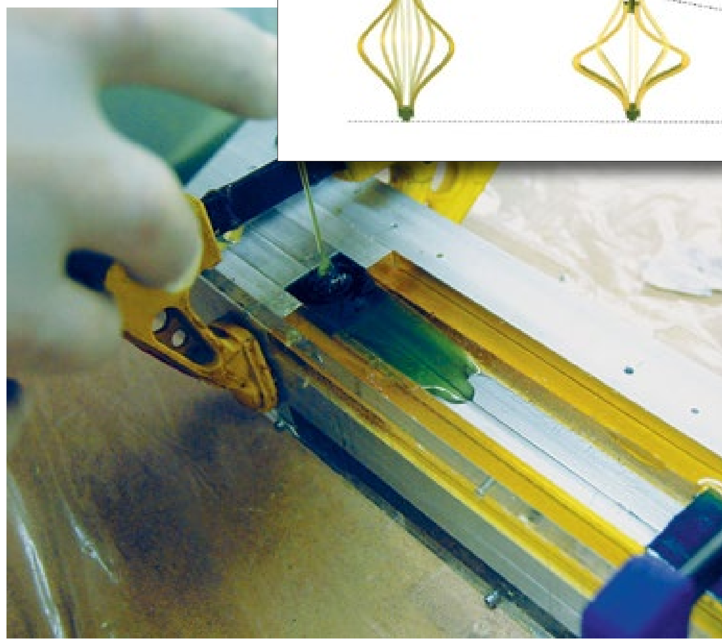
Elastomers
Omar Khan, *Open Columns* (2008) and *Gravity Screens* (2009). Documentation and illustrations of the study and assemblage of elastomers. Courtesy of Omar Khan.

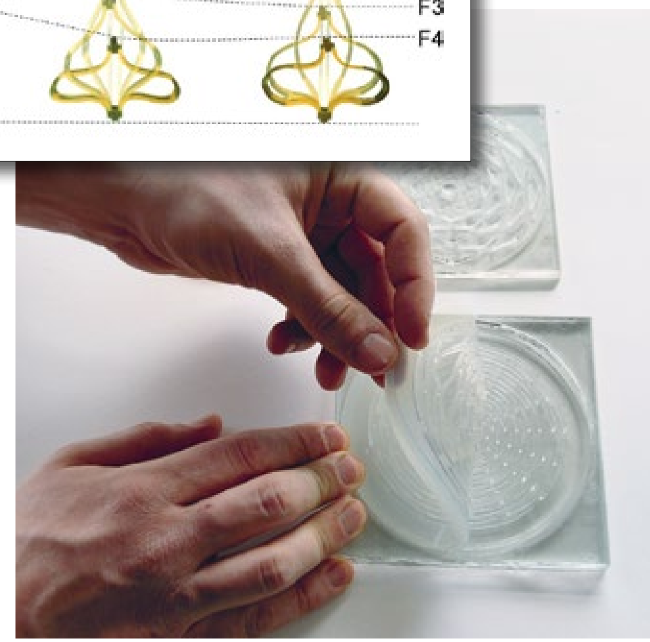












Disas sem

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Disassembling: An Introduction

Consider the construction of a building-to-be: a tall tower is assembled and clad with white marble. With a single act of instruction, the architect creates two distinct entities: a building and also a void. While the building is obvious, the void is not—it exists far away from the building site, in the quarry where the white marble was excavated. This parable, shared by Rotor Deconstruction at a global conference on precarity, aptly describes today's material economies.[1] As more stuff gets built above ground, more stuff gets taken out from below.

Where do these materials go? When a building reaches the end of its lifecycle, the materials originally taken from the quarry are transported to a landfill.[2] With a typical lifecycle of three decades or less, most building materials and components have functionally shorter lives than their human occupants. In fact, the timeline of depreciation coincides with the timeline of a typical mortgage repayment (amortization schedules are typically calculated over 30 years). This overlap between a building's recommended lifespan and the scheduled process of paying off a mortgage reflects a contextualization of a building as a speculative commodity rather than a social necessity.

Of the two activities—building and extracting—only one act is reversible. Buildings can be taken apart, but marble cannot be returned to the earth's crust. *Disassembling* presents design practices that experiment with how buildings come apart, working through notions of obsolescence, dismantlement, and material reuse. Responding to a world dense with things left behind by those who made them, design practices such as After Architecture, Gramazio Kohler Research, HANNAH, and Sutherlin Santo design processes, rather than produce, to facilitate material change through dismantlement.

Many materials become waste before even leaving the production site. Almost 30 percent of marble is discarded on site as "spoils," or marble scraps and sludge produced in the process of cutting and shaping to standard dimensions.[3] Materials are discarded as waste when they fail to align with industrialized manufacturing standards. Similar to marble, nonlinear wood is considered unusable in construction due to the lumber industry's shaping standards. HANNAH's *Unlog* project cuts and peels apart a single irregular (infested or unruly) ash tree log, deemed unsuitable for timber by industrial standards. By working with non-conventional wood supply, HANNAH pairs robotic kerning with augmented reality tools to investigate how far the material of a single log can be stretched. By slicing the piece of wood with specific patterned cuts, and stretching it apart (similar to an accordion), HANNAH is able to produce lightweight A-frame structures. When the structure is disassembled, the wood retracts back into the original log shape, thereby operating like a reversible ready-to-assemble structure or an architectural flatpack. Delaminated Lumber, 198 With *Tangential Timber*, After Architecture

demonstrates how architects can adapt to a supply chain of unused materials. The practitioners designed a material workflow that digitally inventories non-dimensional lumber stockpiles and aggregates them into thin-shell construction architecture. This wood assembly can be installed, dismantled, and reassembled, with the disassembly of the timber "cookies" made possible by a custom joinery system facilitated by digital fabrication. Non-dimensional Lumber, 194

While some practices approach disassembly through designing physical components that join and unjoin, allowing a unique structure to deploy and deconstruct, other practices develop fabrication methods that work with "raw" materials that ultimately dissolve or return to their as-found state. Sutherlin Santo experiments with biopolymer gels and digital fabrication to produce formally and aesthetically customized materials. Using plant-based and natural materials and employing robotic fabrication methods, the studio creates objects, like *Biocraft*, that have an inherent capacity to decay and dissolve. Biogel Sheets, 200 Gramazio Kohler Research explores physical and structural reversibility in construction. *Rock Print* utilizes principles of "jamming," where granular matter such as gravel is tightly packed with a carefully laid-out path of string that "jams" the gravel with just enough added friction to achieve structural stability. When the string is removed, the columnar assembly disassembles, returning the load-bearing column to a pile of string and gravel. Jammed Gravel, 196

In her essay "Disassembling: In Search of Models," design curator Zofia Trafas White catalogues practices interested in recovering materials for future repairs, reconsidering demolition sites and older buildings as stock or inventory for construction, and the design trends leading away from inorganic materials toward renewable and fiber-based materials. Zofia Trafas White, 62 Unlike practices of *Re-fusing*, which rely on the permanent or semi-permanent assembly of matter into useful form, *Disassembling* practices insist on decoupling, taking apart, and the reversibility of material assemblies after their use is fulfilled.

How can buildings be recycled and transformed into sites of source material, bridging the gap between extraction and construction? How can the act of demolition serve instead as an act of provision for future architectures? Concerned with entire lifespans of materials, considering them as processes rather than products, and pushing back against ideas of permanence in architecture, *Disassembling* attends to material economies before and after the act of building.

1 Rotor Deconstruction, "How to Recycle a Building," *The World Around In Focus: Precarity* (lecture conference, Het Nieuwe Instituut, Rotterdam, Netherlands, June 11, 2011).

2 See Table 1 of Carbon Leadership Forum, Recommended guidelines for building component lifespans in whole building life cycle assessment. (Oakland, CA: Carbon Leadership Forum, 2018). https://www.carbonleadershipforum.org/wp-content/uploads/2018/07/CLF_Recommendations_BuildingComponentLifespans_07-06-2018.pdf.

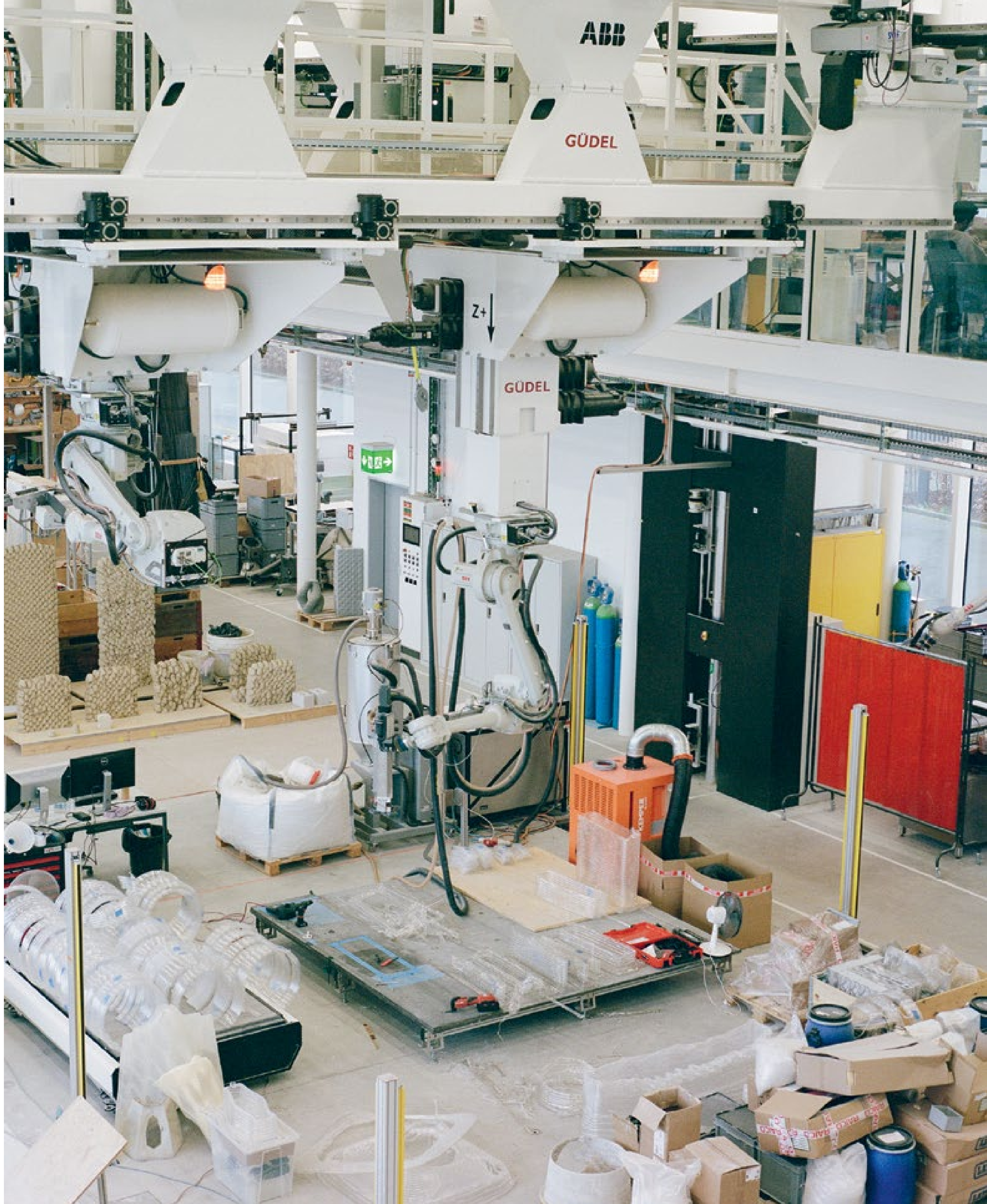
3 V. Liguori, G. Rizzo & M. Traverso. 2008. "Marble Quarrying: An Energy And Waste Intensive Activity In The Production Of Building Materials," *WIT Transactions on Ecology and Environment* 108 (2008): 109.

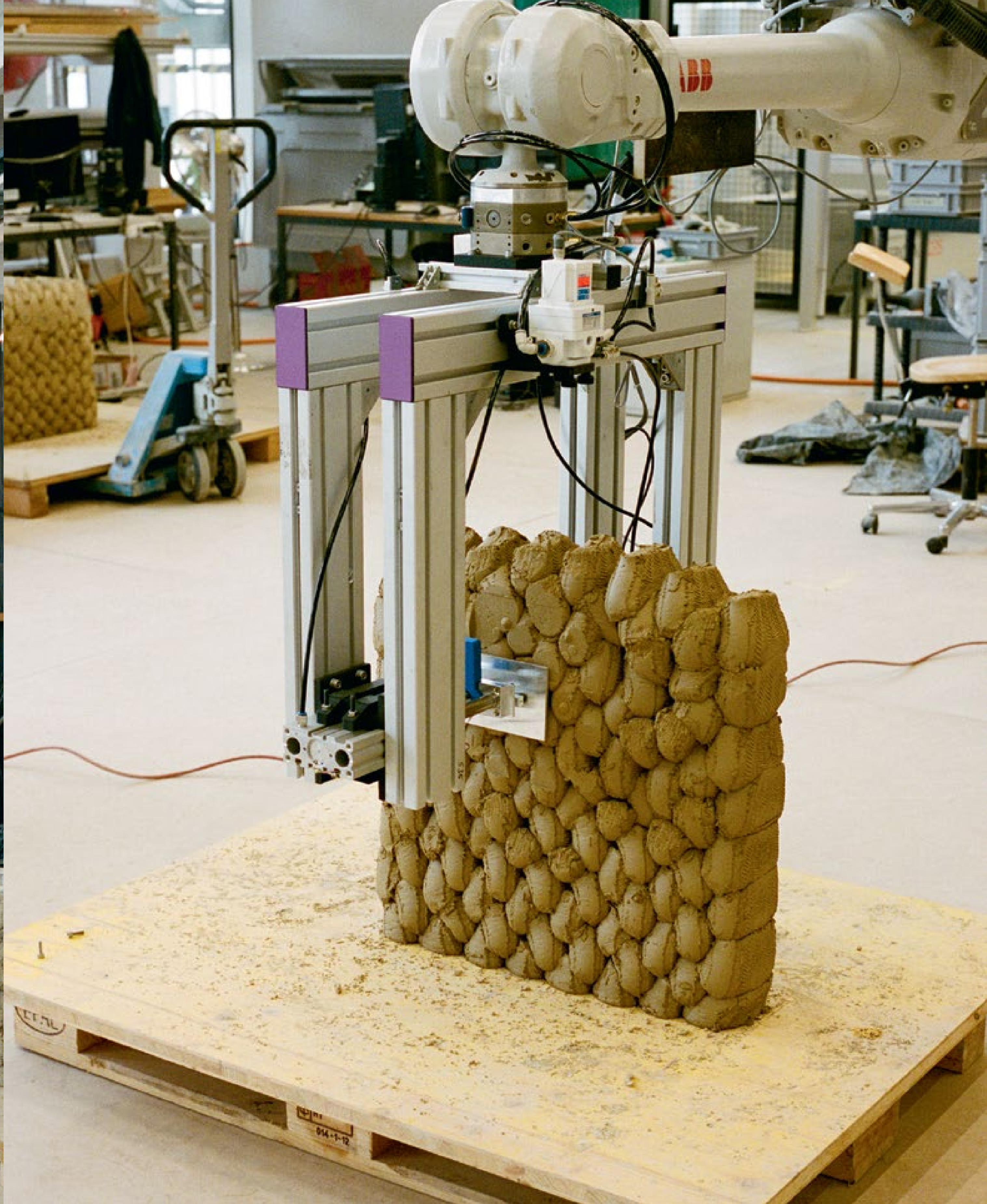
The Classroom Laboratory

Gramazio Kohler Research
Zurich, Switzerland

Jammed Gravel, 196

Photography by Zara Pfeifer

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DISASSEMBLING IN THE CLASSROOM LABORATORY

In Gramazio Kohler Research's laboratory, the classroom is a machine that contains a complex system of motors, robotic arms, wires, tracks, sensors, cables, outlets, and screen attachments—all integrated with an overhead running gantry system housing industrial robots that can work cooperatively. The building itself serves as an armature for enacting material procedures and digital fabrication processes. Adjacent to the fabrication space is an archive and living exhibition of past experiments.

Disassembling: In Search of Models

Zofia Trafas White

A messy context

The explosions that demolished the Pruitt-Igoe building were loud and messy. The series of planned demolitions that began in St. Louis, Missouri, on March 16, 1972, had been initiated by state and federal governments following rising concerns around the deteriorating conditions of the public housing complex, originally built under a regime of New-Deal optimism in urban renewal and centralized planning by renowned modernist architect Minoru Yamasaki. Meticulously planned and controlled, each explosion of the steel-and-concrete building produced a spectacle visible from afar, with dust from the rubble rising high into the sky. With a demolition cost of $3.5 million, it was the first major public housing project in the USA to be destroyed.[1] Televised and widely debated at the time, the demolition event became symbolic of Modernism's end to many social critics and observers in the architecture community.[2]

Viewed through an environmental lens, the televised 1972 Pruitt-Igoe demolition is a poignant reminder of the ubiquitous practice of dismantling buildings by brute force. Built environments of bricks, mortar, concrete, and glass are not designed to be easily taken apart. Whether by dynamite, wrecking ball, or sledgehammer, most processes to this day rely on crude methods that don't often leave much for re-use. And demolition itself continues to fascinate: YouTube alone contains over four million clips capturing building demolitions all around the world, while television documentary series like *Blowdown* (2008) appear to almost glorify their ingenuity.

Demolition of Capital Plaza Tower in Frankfort, Kentucky, March 11, 2018. Photograph by Micah Williams and courtesy of Unsplash License.

1 Eugene Meehan, *The Quality of Federal Policymaking: Programmed Failure in Public Housing* (Columbia: University of Missouri Press, 1979), 112.

2 Katharine G. Bristol, "The Pruitt-Igoe Myth," *Journal of Architectural Education* 44, no. 3 (May 1991): 163–171.

Widespread across the globe, demolition practices today contribute to pressing concerns about the wasteful and damaging environmental impact of buildings. In the context of a growing planetary climate crisis, finding new, more sustainable models of practice that rethink building material lifespans has never been more urgent.

Today's construction industry is a staggering consumer of the world's depleting material resources. Globally each year, nearly half of the materials extracted and manufactured are used for the construction of buildings and infrastructure, much of which, decades after initial use, ends up as a waste.[3] While such patterns continue, materials consumption is only set to rise, with projections that the usage of materials for building projects will double by 2060 across the world.[4] Such turnover of materials mirrors statistics around carbon emissions that warm the climate. As highlighted by architectural historian Barnabas Calder, the construction, operation, and demolition of buildings today are responsible for 39 percent of all greenhouse gas emissions.[5]

The management of carbon in architecture thus spans from the initial design process where materials and their methods of assembly are chosen to the wider systems that look after a building when it is occupied and when it is not. Such processes often fail, however, to plan for the reuse or safe disassembling of a building's components. Across Europe, for example, building waste accounts for approximately 35 percent of total waste generated each year and consists of numerous material types, including concrete, bricks, gypsum, tiles, ceramics, wood, glass, metals, plastic, solvents, asbestos, and excavated soil, most of which ends up in landfills where ongoing deterioration can carry further polluting effects.[6] Useful parts are rarely recovered, and that which is not discarded tends to be downcycled into lower quality product, such as filler for roadbeds or the foundations of new buildings. Rules and regulations, which vary from country to country, around who owns and manages the materials being removed from building sites add further complexity to this picture. Architects campaigning for action in the face of the climate crisis are calling for greater transparency in monitoring the embodied carbon footprint of buildings and greater regulation in the management of demolition building waste.[7]

Designers and manufacturers are also investigating the realities of spiraling building waste through material innovations. For instance, the K-Briq, which is developed by Scottish brick manufacturer Kenoteq Ltd., is made of 90 percent recycled construction waste and uses a low-energy curing process to bond the aggregate material in a formwork, without the need for traditional firing processes. The K-Briq initiative began in 2019 as a research project at Heriot-Watt University in Edinburgh and became a reality only through a successful collaboration with Scotland's biggest waste management company Hamilton Waste & Recycling, who provided gypsum. Following initial testing and accreditation phases, it was released as a commercial product in the UK in Spring 2023 with hopes for wider industry impact.

While such innovations represent some positive steps forward, they are rare and limited as the architecture industry remains stagnant in a system of waste production. Bound up in capitalist economic models of growth, most current construction industry models justify demolishing and building new buildings, opting for cheaper materials over longevity and recycling potential. With such powerful economic forces at play, models of architectural design and fabrication, alongside the building codes that regulate them, need to be rethought in order to make sustainable material flows a norm.

How we take things apart

How things are produced and what materials they are made from can play a defining role in the longevity of a design or how quickly it ends up discarded as waste. From single-use coffee cups to electronics, clothes, furniture, and buildings, waste is a complex force encompassing varied lifespans shaped by a network of actors and interests. It is also a deeply problematic concept that has the potential to be designed out. To do so requires models that rethink fundamental systems that govern how our designed world is made. In this context, disassembling offers an important framework for critically rethinking waste.

Defined as "the action or process of taking something to pieces," the modern usage of the term disassembling in the English language has its origins in military contexts.[8] Around 1872, disassembling was originally used to describe the process of the systematic dismantling of mechanical objects such as small arms. Definitions at the time allude to the speed that such disassembling can happen, time being a critical factor for gun reloading and repairs. Such origins of the term connect to a wider historical moment of the Industrial Revolution when new inventions in mass manufacturing were changing the way machine-produced products were being designed. Military products, such as the American Colt Army Model 1860 revolver became game-changing inventions that perfected the mass production of identical, interchangeable parts. The Colt's design answered calls from a wartime military industry that was struggling with the costs of made-to-order arms that were full of bespoke, hand-crafted parts, time-consuming, and expensive to fix. Innovations in gun designs with interchangeable parts made replacing parts a norm, while also perfecting technologies and precision machinery for the reliable production of identical parts

3 United Nations Environment Programme, 2020 *Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector*. (Nairobi, 2020), 48.

4 United Nations Environment Programme (2022), *2022 Global Status Report*, 72.

5 Barnabas Calder, *Architecture. From Prehistory to Climate Emergency*, (London: Pelican Books, 2022), xi.

6 United Nations Environment Programme, *2022 Global Status Report*, 48.

7 For example, Architects Declare UK https://www.architectsdeclare.com/.

8 Oxford English Dictionary, "disassembling, n.", https://doi.org/10.1093/OED/2702189771.

(as was necessary for reliable military provision). Such principles of parts-based manufacturing then expanded into other factory-made designs for the civilian sphere such as sewing machines, bicycles, and eventually, cars.

Disassembling thus signals a planned process in which component pieces are capable of being joined together and taken apart, and when required, easily replaced. Crucial in the concept of disassembling are "parts." Pre-designed from the outset, they operate as distinguishable, replaceable, and re-useable elements. Beyond the context of precision manufacturing, thinking through parts highlights an important principle of planning for dismantling and the possibility of recovery and re-use of materials. As such, disassembling invites long-term thinking into the process of design. Unlike the pulverized fragments that remain after a messy demolition, parts and reversible material assemblies help to reduce what becomes "waste" in the first place.

Thinking about design as a practice of assembling and disassembling recoverable parts invites important connections to the systems of material flows found in the natural world. Here there is no such thing as waste, as nature operates according to a system of nutrients and metabolisms that create a constant flow of resources. Described as a "cradle to cradle" system by architect William McDonough and chemist Michael Braungart in their eponymous book, the natural world runs as a circular system where "waste equals food" and a network of living species continuously feeds one another.[9] This, they argue, sits in direct opposition to dominant cycles of human production that operate on linear "cradle to grave" models, in which materials are "thrown away."

Drawing on this analysis of natural resource flows, McDonough and Braungart issue a rallying call for remaking the way we make things. Their approach is rooted in biomimicry, a practice that seeks to mimic systems found in the natural world in human designs. In their conception, design should operate on the premise that everything is a resource for something else. They propose two categories of materials, acknowledging that both natural and human-made materials circulate in our world. They argue that through the right material choices, everything has the potential to be designed to be disassembled: either safely returned to the soil as "biological nutrients" through decomposition, or re-utilized as high-quality materials for new products as "technical nutrients" without contamination.[10]

The looming crisis of microplastic pollution serves as a cautionary tale of what happens when this doesn't happen, when the disassembly and disintegration of materials is unplanned.[11] Since their early history as lab experiments in the nineteenth century, plastics have shown signs of instability and unpredictability as a material.[12] Today, there is growing evidence of the far-reaching environmental and health damages caused by plastic breakdown, with safe methods for their dismantlement yet to be found.[13] Designing for disassembling requires taking responsibility for material selection and having foresight of the human and non-human forces that will ultimately act on them. From designing new materials to choosing from existing ones, cross-disciplinary knowledge across design and science is needed to responsibly model the full lifecycle of materials, and ensure that once released into the world, they won't have unplanned, damaging forms of coming apart.

9 William McDonough and Michael Braungart, *Cradle to Cradle. Remaking the Way We Make Things* (New York: North Point Press, 2002), 92–117.

10 McDonough and Braungart, *Cradle to Cradle*, 103–115.

11 Elizabeth Kolbert, "A Trillion Little Pieces. How Plastics Are Poisoning Us," *The New Yorker*, July 3, 2023, 24–27.

Harvesting

Disassembling can operate as an intervention into structures slated for demolition. Here, design practices intervene to find and create parts for re-use, even if they have not been pre-planned. The result captures materials before they are disposed as "waste," prolonging their life as a useful resource. The work of Dutch architecture practice Superuse Studios demonstrates how interventions of disassembling and materials salvage can be drivers of design itself. Since its founding in 1997 by Jan Jongert and Césare Peeren, the studio has been committed to exploring the flows of materials in urban environments and finding ways to maximize their reuse. Today it operates as a collective based in various cities, each member helping instigate strategies for reuse interventions. "Recognizing opportunities are basic capabilities for what may become a new profession: the superuse scout," says Jongert.[14] The "superuse" method sees all buildings through the lens of the component parts they are originally made of, and views disassembling as a tool for extracting these parts for re-use. For the studio, this has translated into both building design projects and online toolkits for materials sourcing.

In 2012, Superuse Studios launched a dedicated online platform, "Oogstkaart" (or "Harvest Map"), to serve as a marketplace for re-circulating reclaimed building materials in the Netherlands.[15] Beyond supplying Superuse Studio's own architectural commissions, Oogstkaart opened their process to external design professionals and project developers. This interactive map captures listings of components recovered from demolished buildings, unsold inventory and stock (known as "deadstock"), and leftovers from industrial manufacturing. The map offers view filters including the location of a product, its material type, quantity, and size. Crucially, it also maps the distance between available materials and the building site they are being "scouted" for. Minimizing the carbon footprint of transportation distances and cutting out needless

12 Mark Miodownik, "Imaginative" in *Stuff Matters. The Strange Stories of the Marvelous Materials That Shape Our Man-Made World* (London: Penguin, 2014), 125–159.

13 Stephen Buranyi, "'We are just getting started': the plastic-eating bacteria that could change the world", *The Guardian*, September 28, 2023.

14 Ed van Hinte, Césare Peeren and Jan Jongert, *Superuse. Constructing new architecture by shortcutting material flows* (Rotterdam: 010 Publishers, 2007), 14.

15 Oogstkaart website: *De urban mining potentie van NL* [Harvest Map. The urban mining potential of NL], https://www.oogstkaart.nl/.

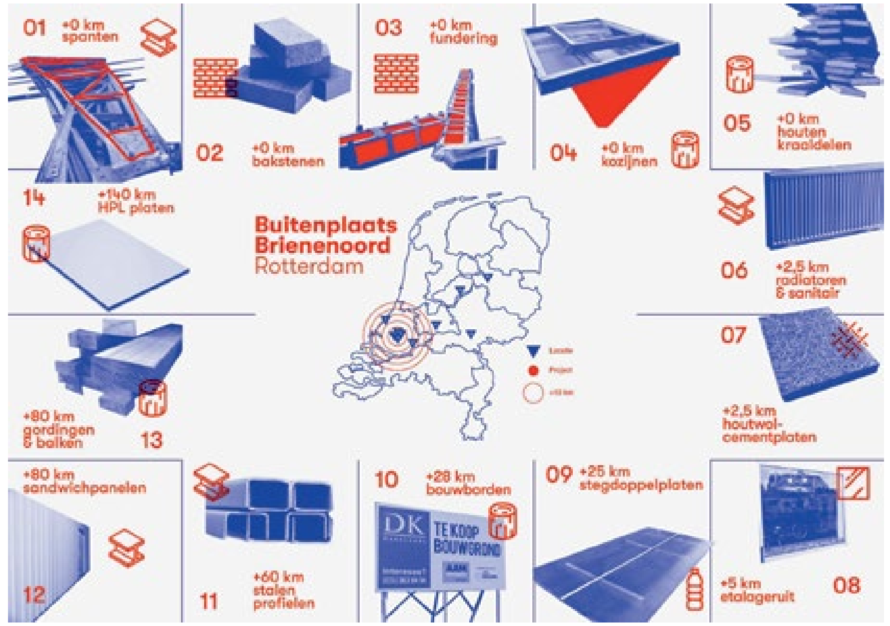
relocation of materials is all part of how “superuse” works as an intervention into resource flows.

Such “harvest mapping” is at the root of each Superuse Studio design project, and often involves starting with the very site of a building commission, carefully examining any existing material or structures already on it. For Buitenplaats Brienenoord, a cultural center in Rotterdam opened in 2020, Superuse devised a design based nearly exclusively on harvested materials, with 90 percent of a pre-existing building’s parts re-used for the new project.[16] The remainder were sourced new, with their distance from the site carefully mapped to minimize the environmental costs of their transport. Such design tactics rely on a strategic collaboration with clients who are open to the process and aesthetics of building with salvaged parts, as well as construction workers who are confident in dismantling and working with reclaimed components. They also require the deft navigation of building codes that require safety and performance certifications for construction materials—regulations that currently still make deploying a reused material a slow and difficult path.

The work of Brazilian practice Arquivo tackles this national specificity of rules for reuse head-on. Founded by Natália Lessa

16 Superuse Studios project website *Buitenplaats Brienenoord*, https://www.superuse-studios.com/projectplus/buitenplaats-brienenoord/.

Buitenplaats Brienenoord building, photograph by Frank Hanswijk. Courtesy of Superuse Studios.



Buitenplaats Brienenoord “harvest map,” courtesy of Superuse Studios.

17 Arquivo website, https://arquivoreuso.com.br/sample-page/servicos/.

and Pedro Alban, the Salvador-based studio operates as a think-tank and consultancy with a mission to simplify reuse processes in architecture. Arquivo’s services include conducting site surveys to determine possibilities for reuse, carrying out the physical removal of reusable components, and selling salvaged building components on their practice website.[17] Recent projects include an online map of reclamation yards in Salvador, mapping local agents for the first time in a centralized way. Arquivo acknowledge themselves as facilitators that help link up diverse actors already operating, with the ultimate aim of building momentum for what they call a “functional reuse industry on a national scale.” To this end, they see architectural education around reuse strategies as critical. Their practice is currently a provider of online courses for any practitioners seeking training in this field, welcoming attendees local to Salvador and from across the globe.

The right to repair

Alternative strategies of disassembling move further up the chain of design decisions to consider the design of re-usable parts from the outset. Speaking to McDonough and Braungart’s concept of design with “technical nutrients,” these tactics create designs based on parts for future disassembly and circular re-use. Such “technical nutrients” are materials or products that are designed to go back into the technical cycle of production from where they came. Planned with re-usable, easy-to-break down component parts, these can be re-utilized or easily repaired with minimum

Image courtesy of Fairphone.

intervention, circulating in closed loops as resources, not "waste." Known as "design for disassembling," such practices are emerging across diverse fields and scales of design, from electronics to furniture and buildings.

First launched in 2013, Fairphone, for instance, challenged industry norms of unrepairable "black box" electronic devices and planned obsolescence. Created by Bas Van Abel and Tessa Wernik with a team of international collaborators, Fairphone is committed to ethically-mined component minerals, fair factory worker conditions, and a right-to-repair built in from the start.[18] Now in its fifth design iteration, Fairphone continues to be based on a unique kit of parts design complete with do-it-yourself repair instructions, enabling any user to disassemble their device, add upgrades, and prolong its life. Together with wider campaigns for the "right to repair" led by online communities such as iFixit.com and growing networks of specialist repair trades, the power of such designs is beginning to show in the shifting landscape of legal frameworks and industry commitments to design for disassembling and device repair. For instance, in California, home to Silicon Valley, a new "Right to Repair Act" (SB 244) that guarantees consumers access to parts and instructions that enable them to fix devices was passed in October 2023, aided by a surprise U-turn from tech giants like Apple itself.[19]

Design for disassembling can also be found as an emerging strategy in furniture product design. British company Benchmark Furniture offers an example of a business model built around the idea of product longevity and circular re-use of parts. Rooted in a commitment to sourcing all its wood from forestry-certified sources, their furniture is designed to be easily taken apart for repair and reuse. Designs use robust solid woods and natural oils and avoid chemical glues that would make disassembly difficult. The firm offers a "Lifetime Repair" service, encouraging

18 Damian Carrington, "$10bn of precious metals dumped each year in electronic waste, says UN", *The Guardian*, July 2, 2020.

19 Brian Merchant, "Apple has fought the right to repair devices for years. Why did it just make a U-turn?" *Los Angeles Times*, August 25, 2023.

refurbishment or redesign, rather than replacement, alongside a "Take Back Scheme" for customers.[20] As with Fairphone, building care for parts into the logic of a design is predicated on a longer-term relationship between company and customer. Wider applications of such principles in more mass reach contexts, such as IKEA, are also being developed.[21]

Translating such strategies to the context of architectural design remains a challenge, not least because of the complexity and scale of a building's component parts and the skills and labor needed to safely dismantle them. However, the fundamental principle of transparency around component parts holds the key to how materials can become "technical nutrients" for material flows. A growing movement of architecture practices is working to create so-called "material passports" to address this very issue. Essentially digital documents that collate data on all component parts that go into a building, "passports" aim to make future parts analysis, repair, and disassembling easier, and help tackle the often complex legal and financial side of assessing reusable parts. The concept was pioneered by Dutch architect Thomas Rau, co-founder of Turntoo and RAU, who abides by the philosophy that "waste is a material without an identity." He has called for a commitment to mapping all materials that go into buildings and devised the digital platform Madaster (a "cadaster for materials and products") as a toolkit for the industry.[22] Variants of digital platforms generating "material passports" for building projects continue to emerge.[23]

Decomposition

Design for disassembly can extend beyond industrially-made, technical parts to strategic thinking about natural processes of coming apart through decomposition. Materials of natural origin, when used without toxic chemical treatments, offer the potential of biodegradable products and buildings. Here, naturally derived component parts of a design carry an inherent potential to come apart through natural breakdown processes, removing the risk of becoming polluting waste from the outset. Such models of sustainable making speak to McDonough and Braungart's concept of design with "biological nutrients," where material assemblies have a planned afterlife beyond human uses, in wider ecosystems of materials flow. Rooted in ecological knowledge and commitment to long term thinking, such practices willingly open human-made products and structures to the agency of diverse non-human actors, embracing the power of natural metabolisms to take things apart slowly and re-circulate their nutrients where needed.

Models of such practice abound in the rich vernacular traditions of natural building found in diverse Indigenous communities

20 Benchmark, *Made WELL Sustainability Report 2023*, 38–40, https://benchmarkfurniture. com/wp-content/uploads/2023/05/ BM_made_well_report_2023.pdf.

21 Tim Nelson, "IKEA Wants You to Take Apart Its Furniture," *Architectural Digest*, February 25, 2021.

22 Thomas Rau and Sabine Oberhuber, *Material Matters. Developing Business for a Circular Economy* (London: Routledge, 2022).

23 Isabella Kaminski, "Material passports: finding value in rubble," *Architects' Journal*, August 8, 2019.

Samples created by the Making with Earth class at Columbia University, instructed by Lola Ben-Alon. Photo courtesy of Lola Ben-Alon and the Natural Materials Lab.

around the world.[24] Such construction systems sit outside of typical Western definitions of building technology and "modern" materials such as steel, concrete, and glass, instead foregrounding use of natural materials that form a cohesive part of local ecosystems. As a material for building, earthen matter typically involves low carbon emissions. It does not require industrial processing and needs little to no transportation, being sourced from its immediate locality. A centuries-old building construction technique, rammed earth architecture can be found across India, Mali, Burkina Faso, and beyond.[25] Processed by hand or pressed into "bricks" through formwork molds, the key components of rammed earth structures—including walls and floors—are unfired and require only solar heat to harden. In the hands of skilled craftspeople, they are capable of being assembled without the use of cement or other non-compostable stabilizers, and as such have the potential to exist as fully recyclable structures.

Design education is turning to Indigenous building practices for design inspiration.[26] Education efforts are underway to rebuild the traditional ecological knowledges that underpin such design

24 Sandra Piesik, ed. *Habitat: Vernacular Architecture For a Changing Planet* (New York: Harry N. Abrams, 2017).

25 Jean Dethier, "Inhabiting the earth: a new history of raw earth architecture," *Architectural Review*, January 31, 2020.

26 Julia Watson, 'Introduction. A Mythology of Technology', in *Lo-TEK, Design by Radical Indigenism* (Cologne: Taschen, 2019), 16–27.

practices, once passed down through intergenerational communities, but now at risk of being lost as forces of globalization push local architectural traditions out. In the Himalayan region of Ladakh in northern India, for example, a new university, the Himalayan Institute of Alternatives Ladakh (HIAL), has been created with the vision of reviving knowledge of Indigenous construction and engineering techniques, as well as farming practices.[27] Founded by social entrepreneurs and educators Sonam Wangchuk and Gitanjali J Angmo, the HIAL educational model is rooted in connecting design to its local ecosystem. Students learn by doing as contributors to the ongoing construction of HIAL's low-carbon campus. Building on the traditions of Ladakh's historic rammed earth architecture, the programs also introduce new techniques for raw earth building and teach students the principles of sourcing hyperlocal materials for construction.[28]

Translating such experimental research practices to the wider architecture sector remains rare. Mainstream construction economies make building with natural, fully biodegradable materials challenging: requirements for material certifications remain lengthy processes, while construction sector knowledge of how to safely build with natural components is rare and often requires new training. Step changes can happen with industry collaboration right from the start. Projects like Atelier LUMA, designed by London-based Assemble Studio and Belgian BC architects for the Arles-based LUMA Foundation in France, point to new models of building with natural, biodegradable materials. Rooted in lab-based materials research and collaboration with diverse local industries, the project pioneered building applications for materials as diverse as rice straw, sunflower stems, salt, soil, and limestone waste. Testing the viability of such materials with construction partners early in the process enabled their application on a pioneering scale, translating them into acoustic and thermal insulation, and rammed earth walls.[29] The result is a bio-regional architecture that puts sustainable material flows, and connections with diverse custodians of materials, at its core.

Across a diversity of formats and design contexts, disassembling can be a powerful strategy for sustainable making. From interventions to reclaim parts to an expanded field of safe decomposition, it offers the opportunity to rethink the troubling principles of "waste" that still govern our world. As a creative and subversive act, it invites design practice to have a greater agency in economic systems. In its push for more sustainable alternatives, the human-made world becomes a respectful part of a wider ecology, a wider web of planetary life.

27 Himalayan Institute of Alternatives, Ladakh, Vision Statement, https://hial.edu.in/vision-mission-values/.

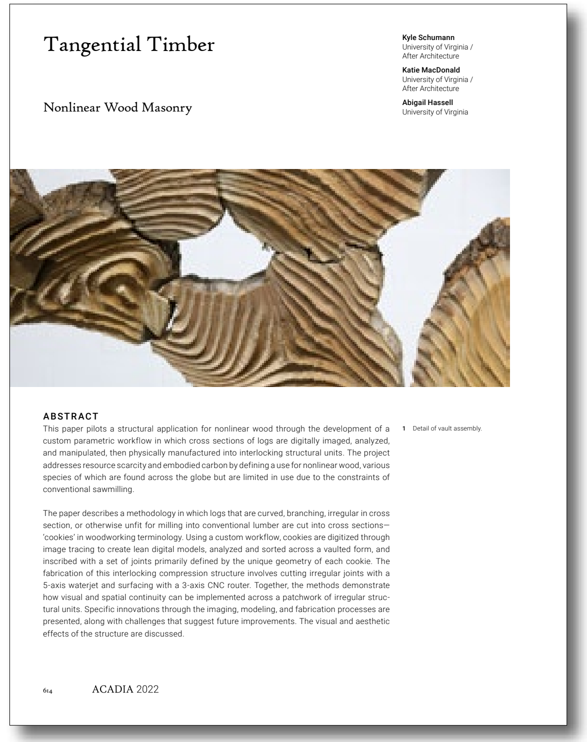
28 Translating such thinking to urban educational contexts is also gathering momentum. For example, at the GSAPP Natural Building Materials Lab at Columbia University in New York City, architectural researcher Lola Ben-Alon leads a new teaching program dedicated to experimenting with natural clays and new robotic manufacturing technologies. Drawing on a range of local clays, students of the program experiment with recipes for non-toxic materials and investigate the potential of computer-aided design meeting century-old earth building practices.

29 Malaika Byng, "Magasin Électrique opens in Arles as the home of material pioneer Atelier Luma," Wallpaper.com, May 30, 2023. https://www.wallpaper.com/architecture/the-magasin-electrique-assemble-arles-france.

How to Cut Cookies

After Architecture

The formats of material inscriptions are tailored to their intended audience, highlighting the significance of community for the dissemination of specialized knowledge in experimentation. In 2022, After Architecture presented their *Tangential Timber* project at the annual ACADIA (Association for Computer Aided Design in Architecture) Conference, where architectural research is subjected to a scientific demonstration of research. Non-dimensional Lumber, 194 ACADIA supplements the educational event with a book of conference proceedings that include articles, each beginning with an abstract that summarizes the project for the publication's audience.



Tangential Timber

Nonlinear Wood Masonry

Kyle Schumann
University of Virginia / After Architecture

Katie MacDonald
University of Virginia / After Architecture

Abigail Hassell
University of Virginia

ABSTRACT

This paper pilots a structural application for nonlinear wood through the development of a custom parametric workflow in which cross sections of logs are digitally imaged, analyzed, and manipulated, then physically manufactured into interlocking structural units. The project addresses resource scarcity and embodied carbon by defining a use for nonlinear wood, various species of which are found across the globe but are limited in use due to the constraints of conventional sawmilling.

The paper describes a methodology in which logs that are curved, branching, irregular in cross section, or otherwise unfit for milling into conventional lumber are cut into cross sections—'cookies' in woodworking terminology. Using a custom workflow, cookies are digitized through image tracing to create lean digital models, analyzed and sorted across a vaulted form, and inscribed with a set of joints primarily defined by the unique geometry of each cookie. The fabrication of this interlocking compression structure involves cutting irregular joints with a 5-axis waterjet and surfacing with a 3-axis CNC router. Together, the methods demonstrate how visual and spatial continuity can be implemented across a patchwork of irregular structural units. Specific innovations through the imaging, modeling, and fabrication processes are presented, along with challenges that suggest future improvements. The visual and aesthetic effects of the structure are discussed.

614 ACADIA 2022

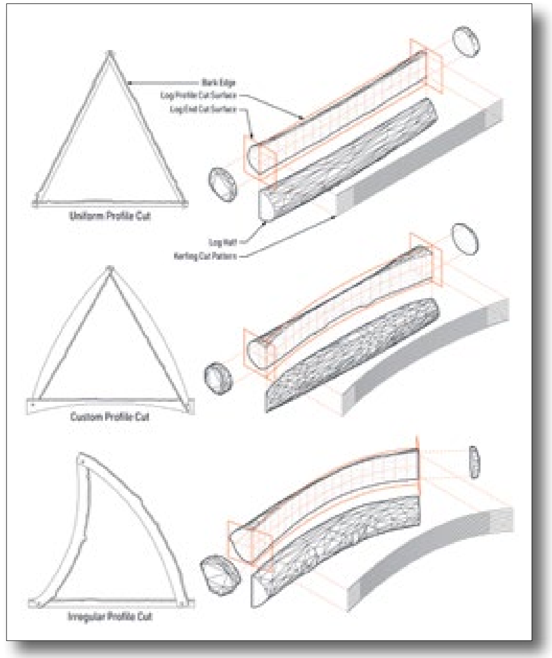
Timber Cookies
After Architecture, "Tangential Timber," ACADIA 2022. Article in the proceedings of the 39th Annual Conference of ACADIA. Courtesy of After Architecture.

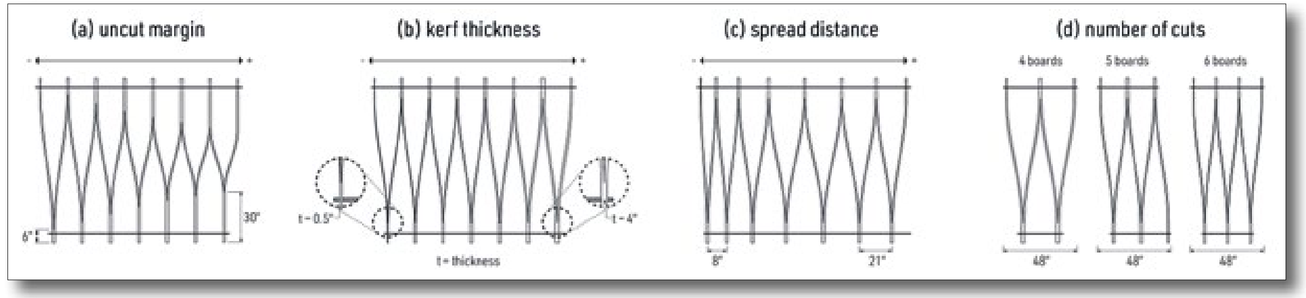
How to Unlog

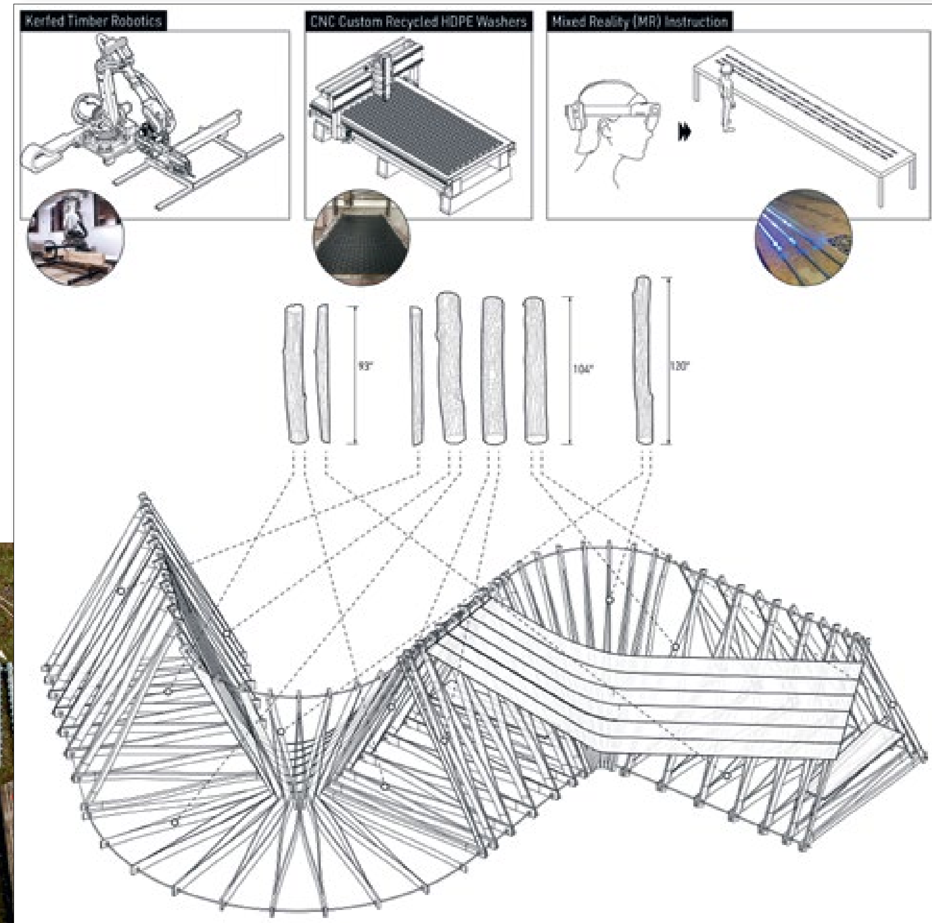
HANNAH

Many material experiments are time-based and step-wise processes that are best represented through illustration, yet often the tools and instruments of production are left out of the picture. Instructions from HANNAH's *Unlog* research incorporate a visual trajectory of how wood is transformed from raw material to finished product. Delaminated Lumber, 198 In an effort to illustrate the multi-medial process which incorporates a 3D scanner, mixed reality goggles, and robotic arm, HANNAH has incorporated illustrations of the technology necessary to determine precise and individually differentiated cuts to non-standard wood logs.

Delaminated Lumber
Diagrams showing process of robotically kerfing logs that cannot be processed into standardized lumber. Courtesy of HANNAH.







Fe ed.

Feeding: An Introduction

Present-day material productions, such as fossil fuel drilling, mineral mining, concrete mixing, and industrialized forestry, are highly extractive and carbon-intensive processes. In an effort to move away from developing materials that rely on extractive techniques and processes, contemporary designers are asking and looking to answer how built environments can be *grown* with living systems.[1] Acts in *Feeding* highlight design experiments that incorporate living organisms into material fabrication. Also known as biofabrication or biotechnology, the science of redirecting metabolic life towards human use has applications across an array of sectors, including in the bioprinting of human tissues and organs; in regenerative energy production through oils extracted from algae; and in the growth of animal-free or cultured meat.[2] Design and architecture practitioners are developing skins, structures, and artifacts from live materials such as cells, bacteria, yeast, algae, and mycelia. In contrast to acts of *Animating*, which approximate living systems by activating inert materials, acts of *Feeding* harness the metabolic activities of living organisms to produce the components of architecture. Thus, bacteria and fungi "co-perform" with human actors.

Artist and chemist Maru Garcia intervenes in the early stages of a material's development by growing bacteria into building skins, composing thriving environments for the cellulose growth of symbiotic cultures of bacteria and yeast (SCOBY)—the naturally occurring and edible cultures found in kombucha. Bacterial Cellulose Sheets, 206 The byproducts of the bacterial cultures are then harvested and deployed as thin, architectural membranes. In other practices, metabolic activities are redirected to enhance structural performance and open new pathways for form-making. In Christine Yogiaman's *Living Forms*, 3D-knit textiles are used as formwork, or molds, for mycelium-based composites. Building upon fungi's capacity to transform dead matter into new life, Yogiaman and collaborator Mycotech feed mycelia networks with lumber and agricultural waste before stuffing them into textile molds. These molds guide the open-ended process of mycelia growth, which are in turn heated in an oven, depriving the mycelium network of oxygen. In the heating, the living system dies and calcifies into structural columns. Mycelium Columns, 204 Working between her university laboratory and a biotechnology start-up, Yogiaman's research traverses many sites of production, from the mycelium biofabrication factory to the digital desktop of 3D knitting. The Farm and Factory, 82 Similarly, in the research practice of Soft Matters (led by Aurélie Mosse), populations of organisms are embedded directly into material systems. The project *ImpressioVivo* incorporates the 3D printing of biomaterials with bioluminescent and calcifying bacteria. Biocalcified Paper Foam, 208

Processes that redirect living organisms and their life cycles offer a critical step towards regenerative and circular systems, where naturally recurring cycles of growth and decay offer alternatives to the exploitation

of non-renewable resources. Designing the built environment with living organisms also raises important questions and ethics of care, through which stewardship guidelines, non-human labor, and definitions of life arise. These considerations, as reflected upon in a conversation between Caroline A. Jones, Maru Garcia, and Assia Crawford, involve a reorientation of values necessary for the fostering of life—or the domestication of living organisms. *Feeding* Conversation, 100 As Jones reminds us, "Materials, especially those produced under the pressure of newness and scalability, are the products of co-evolution and domestication." Materials are not simply found in nature nor are they simply "invented"—they are extracted, processed, regulated, sold, speculated, and domesticated.

In her essay "Feeding: Metabolic Symbiosis and Cohabitation," Amy Zhang crosses further into territories of animal labor, reflecting on how animal life-cycles have become infrastructure for other life forms, including ours. Amy Zhang, 94 In her anthropological research, she visits and observes a bioconversion company outside Guangzhou, China, that has converted a former pig farm into an experimental rearing station for black soldier fly larvae (*Hermetia illucens*). These soldier fly larvae are raised to consume agricultural waste and are then converted into foodstock for aquaculture and poultry. As Zhang writes: "The life-cycle of the fly becomes an infrastructure of life-support… This process doesn't just produce waste to be managed, displaced, or contained: it creates matter specifically engineered to support the growth of other life forms." Noting the transformation from a family pig farm into an industrial fly factory, Zhang reflects on how scales of cohabitation also transform the relationship between humans and their animals-as-commodity. In her conversation, Jones similarly contextualizes differing scales and modes of cultivation as the difference between *gardening* and *agriculture*.

How does one domesticate and work with living beings? How can one design ethically with and through animal labor? In sustaining liveness, how can acts of *Feeding* reorient the relationship between two organisms (the designer and the living system) towards commensalism? Experimenting with living systems as generators of our built environment asks us to renew our attention to non-living agents in the cultivation of new materials. As designers ferment, grow, calcify, and harvest material inventories, such acts require us to re-center notions such as symbiosis, sustenance, and maintenance within material experimentation and processes.

1 This shift of thinking from circular *energy* to circular *matter* is articulated by Deb Chachra in *How Infrastructure Works*: "For all of human history, we've been living like energy is scarce and matter is infinite, when the opposite is true: we need to learn to live like we have access to unlimited energy, but with deep understanding that the atoms we have to work with are part of a closed system. Clean, abundant energy will open all kinds of technological possibilities, but we'll need a deep society-wide rethink of our relationship to matter, extraction, consumption and waste." Deb Chachra, *How Infrastructure Works* (New York: Riverhead, 2023).

2 On bioprinting, see Jinah Jang et al., *Organ Printing (Second Edition)* (Bristol: IOP Publishing, 2023). On algae as fuel, see Michael A. Borowitzka, "Energy from Microalgae: A Short History," in *Algae for Biofuels and Energy*, ed. Michael A. Borowitzka and Navid R. Moheimani (Dordrecht: Springer Netherlands, 2013), 1–15. On cultured meat, see Franziska Brigitte Albrecht et al., "Biofabrication's Contribution to the Evolution of Cultured Meat," *Advanced Healthcare Materials* 13, no. 13 (2024).

The Farm and Factory

Yogiaman Tracy Design and Mycotech
Bandung, Indonesia

Mycelium Columns, 204

Photography by Katariina Träskelin




Gyproc

FEEDING IN THE FARM AND FACTORY

Against a backdrop of palm trees and crop harvests, the Mycotech mushroom farm merges diverse labor practices, entangling Indonesian workers, who pack and fill mycelia substrates into textile molds, with the weaving machines that machine-knit the molds over 1000km away at the Singapore University of Technology and Design. Mycotech is a green-gabled warehouse surrounded by fields and, beyond their collaboration with Yogiaman Tracy Design, the company produces various mycelium products such as fungal leather and mushroom panels. To produce *Growing Scaffold*, workers set up a pre-tensioned Y-shaped textile, stretched across an aluminum jig, before filling it with a mixture of woodships, tapioca, wheat bran, lime, and mycelia. This hybrid system is then baked to produce a robust structural module for construction. This process reflects a cross-section of knowledge production and human actors—farmer linked with designer—representing the diverse economies of labor and knowledge production that enable material experimentation.

Feeding: Metabolic Symbiosis and Cohabitation

Amy Zhang

In 2018, I visited a family farm in a village about an hour and a half outside of Guangzhou. Ducks and chickens wandered the yard next to a large aquaculture fish pond. It was a typical farm in southern China.[1] Up a small, gentle incline sat an enclosed structure, a former pig-pen. Since the early 1980s, China has been concerned with increasing domestic pork production in order to keep up with growing consumer demand. The result is that over the last decade, pigs have been gradually ushered off household farms like this one, and into new, modern industrialized farms. In 2022, an agriculture company unveiled China's first vertical hog farm in the city of Ezhou, a twenty-six-story high-rise building, the latest experiment in intensified hog-raising.[2] Inside the megafarm, which resembles an apartment block, the company expects to raise 25,000 pigs a year on each of the twenty-four breeding floors.

The vertical megafarm is an extreme manifestation of the logics and techniques of factory farming: enclosure, intensification, automation, and standardization. China is faced with the challenge of how to feed 21 percent of the world's population on 9 percent of its arable land. The ushering of hogs away from rural smallholdings and family farms and into megafarms is an experiment that proponents hope will resolve long-standing fears about food shortages and insecurity, which are only increasing in a time of climate anxiety and dwindling land.[3] These experiments promise to leverage techno-science to accelerate and intensify animal growth to satisfy human appetites.

A typical family farm in Guangzhou. Inside the former hog house, a biotechnology company is experimenting with rearing black soldier flies as a new form of feed and protein. Photo by Amy Zhang.

1 A household farm is distinct from backyard farms, a farm that raises fewer than five pigs per year, and large-scale factory farms. A household farm specializing in hog production typically operates with an annual pig production of between 10 to 500 pigs per year and accounted for the majority of pigs raised in China in 2009.

2 Daisuke Wakabayashi and Claire Fu, "China's Bid to Improve Food Production? Giant Towers of Pigs," *New York Times*, February 8, 2023.

3 Mindi Schneider, "Feeding China's Pigs," Institute for Agriculture and Trade Policy, May 17, 2011.

Back on the family farm, the old pen did not sit empty. A biotech startup had converted the former pig-pen into an experimental rearing station for black soldier fly larvae (*Hermetia illucens*), a common and widespread species belonging to the family *Stratiomyidae*. The fly larvae consume agricultural waste and hog manure and, once grown, are sold as feed for aquaculture or poultry. Food companies, meanwhile, have started to promote insects as a widely available and affordable food source. This startup, in particular, was looking into grinding up the larvae in order to market it as a protein-rich food supplement for people.

An array of concrete boxes arranged in a grid, each approximately a square meter in area, spanned the length of the dimly lit former pig-pen. These units corresponded to developmental stages of the fly larvae (larval, pre-pupal, and pupal). Local villagers tend to each trove, measuring and adjusting the temperature, humidity, and light to ensure optimal conditions for fly growth. Here, human caregivers and fly larvae both perform different types of labor, with villagers performing the daily labor of rearing while fly larvae perform the vital metabolic work of consumption, growth, and death.

Thinking about the contemporary ecological crisis, it can be helpful to see human life through the prisms of other forms of life.[4] The connected stories of hogs and flies suggest new configurations of feeding, dwelling, and care emerging in the face of increasingly dense urban environments and ecological precarity. In the early decades of the twenty-first century, techno-scientific experiments in feeding have subjected both porcine and insect life to the same logic of industrial farming: their lives are captured by and subjected to human manipulation to fuel urban food production. The rearing of fly larvae, however, speaks to a more complex narrative. In the pig-pen, a more sustainable human food system relies on the symbiosis and conjuncture of human, porcine, and insect life.[5]

Marxist ecologists have used the concept of the "metabolic rift" to describe the disjuncture that emerged between agricultural production and the return of nutrients to the soil under industrial capitalism.[6] The metabolic rift has been employed to index an increasing disjuncture between nature and ecology under capitalism. However, in the black soldier fly experiment, feeding generates metabolic relationships not only within a single animal body but configures relationships between animals, plants, microbes, and humans such that they are, in the words of Hannah Landecker, "selectively augmented and reconnected anew."[7] At the same time, feeding demands and generates what Lynn Margulis refers to as "systems in which members of different species live in physical contact."[8] Feeding produces systems of cohabitation, of how humans dwell *beside* and *alongside* other life forms.

4 Achille Mbembe, "Futures of Life and Futures of Reason," *Public Culture* 33, no. 1, (2021), 13. https://doi.org/10.1215/08992363-8742136.

5 Donna J. Haraway, *Staying with the Trouble* (Durham, NC: Duke University Press, 2016) and Anna Tsing, *The Mushroom at the End of the World*, (Princeton University Press, 2015).

6 John Bellamy Foster, *Marx's Ecology: Materialism and Nature*, (New York University Press: 2000).

7 Hannah Landecker, "The Food of Our Food: Medicated Feed and the Industrialization of Metabolism," in *Eating besides Ourselves: Thresholds of Food and Bodies*, (Durham, NC: Duke University Press, 2023), 57.

8 Lynn Margulis, *Symbiotic Planet*, (New York: Basic Books, 1998), 5.

9 Les Beldo, "Metabolic Labor: Broiler Chickens and the Exploitation of Vitality," *Environmental Humanities* 9, no. 1, (2017). https://doi.org/10.1215/22011919-3829154.

10 Maan Barua, *Lively Cities*, (Minneapolis: University of Minnesota Press, 2023).

The black soldier fly experiment envisions the developmental stages of the organism as a tool of bioconversion. Insect life thrives on organic waste as a biological substrate, and in so doing, reduces the metabolic rift. The life-cycle of the fly becomes an infrastructure of life-support, a system of circulation that mediates and facilitates the circulation of both nutrients and waste. The phases of the animal's life-cycle perform the metabolic labor of digestion, processing, and excretion.[9] This process doesn't just produce waste to be managed, displaced, or contained: it creates matter specifically engineered to support the growth of other life forms. Insect metabolism is a key site where life-forms are differently re-membered and recomposed. The coordination of the life-cycles of hogs, flies, and humans leads to a symbiosis in which metabolic functions of different life forms are interdependent and ensure mutual survival. The nutrients produced and excreted by one life form support the growth and nourishment of another.

Imagining the fly life-cycle as a tool of bioconversion fits into a long history of treating organisms as machines. From GMOs to synthetic biology, science has targeted animal and plant life as sites to automate, intensify, and scale growth for human purposes. Fly-breeding, however, makes clear the necessity of human cultivators. Fly-rearing deploys strategies long used in animal husbandry: the manipulation of the rhythm, speed, and time of breeding, and the control of temperature and light. More importantly, cultivating flies requires that the human caregiver carefully attune to the tempo and rhythm of fly life. Farmers have long been sensitive to how animal growth-cycles are susceptible to their surroundings. Systems of metabolic symbiosis invite humans to orient their own routines and habits toward the tempos and rhythms of other life forms.

A black soldier fly pupa. Photo by Amy Zhang.

Feeding is not only a question of how we might cultivate animals as food. The story of the hog and fly raises questions about the spaces and arrangements of human and animal life, about how humans and non-humans can live together.[10] Cities in China are increasingly marked by verticality and density. Density incites concerns with biosecurity, the need to protect humans from the transmission of disease. The containment and displacement of waste and the separation of human and non-human life have long been strategies to manage disease and outbreaks. In an age of microbial anxiety, interspecies separation dominates spatial imaginaries of safety, security, and modernity.

The vertical pig-towers of Ezhou project technoscientific imaginaries of human control within dense spaces of animal dwelling. Vertical towers restrict and fix animal movement, closed-circuit televisions monitor animal movement, and strict protocols are put in place to manage the risk of outbreaks. However, in Ezhou, as with factory farms in the United States, industrial agriculture does not enact interspecies separation as much as it creates a condition of interspecies contact. At every stage, as workers enter the confined spaces of hog breeding to provide routines of care, their bodies come into intimate contact with the industrialized pig, sharing in its landscape of disease. Industrial rearing is fundamentally a project in which the labor of specific populations is reconfigured around and exploited through different aspects of animal biology.[11] It perpetuates the myth of automation and interspecies separation, even as human workers' lives are coordinated to that of the industrialized hog.

Fly-raising at the former pig-pen points toward an alternative mode of human-animal cohabitation. The family farm has traditionally been a site of intimate contact between animals and humans. They remind us of care arrangements that contrast with the alienation of industrial labor, which sees animals, their bodies, and life-cycles as commodities. On family farms, cultivators frequently come to care for animals as kin.[12] In an age of ecological crisis, the question of how to perpetuate life might be approached through recognizing the interspecies nature of dwelling and creating space such that human habitats become more open and hospitable to other life forms.[13]

11 Alex Blanchette, *Porkopolis* (Durham, NC: Duke University Press, 2020).

12 Radhika Govindrajan, *Animal Intimacies* (University of Chicago Press, 2018).

13 Anna Lowenhaupt Tsing, Nils Bubandt, Elaine Gan, and Heather Anne Swanson, eds., *Arts of Living on a Damaged Planet* (Minneapolis: University of Minnesota Press, 2017).

Black soldier fly adults. Photo by Amy Zhang.

Margulis shows that at the cellular level, evolution is a process of symbiosis, where the cohabitation between different kinds of organisms can result in symbiogenesis, the formation of new organisms through symbiotic mergers.[14] Cohabitation opens up the potential for transformation, the merging and creation of new bodies and systems. Feeding reminds us of the need to forge relations of symbiosis and cohabitation, of a need to orient relations between humans and non-humans towards mutual survival.

14 Margulis, *Symbiotic Planet*, 33.

Assia Crawford, Maru Garcia, and Caroline A. Jones on Feeding

What follows is a conversation on the material act of feeding with designers and thinkers Maru Garcia, Caroline A. Jones, and Assia Crawford, and the *Material Acts* team. Feeding highlights practices that incorporate and maintain living matter as part of a material fabrication process.

We wanted to begin by asking you, Caroline, about the roundtable discussion you organized, "Syn /\ Sym: Biology in Art and Design," in correlation with the opening of your exhibition *Symbionts: Contemporary Artists and the Biosphere* at the MIT List Visual Arts Center. In the discussion, you described the challenges of studying symbiosis, particularly of living agents that depend on networks of sustaining relationships, because the scientific model demands the isolation of the object of study.

Working with living matter requires a recognition that materials themselves have agency. This means designers must shift their relationship, status, or role in respect to a material they may need to feed, engaging in a more collaborative and intimate exchange. Can you elaborate on the shifted role of the designer or artist?

CAJ Symbiosis research is really challenging and undervalued. It doesn't fit into capitalism, so as a species, we need all the help we can get to advance, praise, honor, and celebrate this work because support is not flowing from institutions like the National

Science Foundation. This research has been around for close to 150 years and it is constantly struggling. It's like how Greek polychromy has always struggled because the whitening discourse of antiquity is always going to hammer it down and say no, we're not going to pay attention to this.

Symbiosis is a big structure that we need designers to help us rethink. As Jessica Varner's dissertation reminds us, we're stuck with Sigfried Giedion's thinking that architecture's all about glass and steel, when it's really about chemicalization. It's about biocides impregnating everything so that modernism can be permanent. There needs to be a total paradigm shift in the design professions, which, depending on who you ask, produce close to 40 percent of greenhouse gas emissions.

There's a story about Biosphere 2 that didn't quite make it into *Symbionts*. Biosphere 2 was built by architects who considered architecture to be static and non-active. However, the concrete was biotically active, constantly taking oxygen out of the atmosphere and suffocating the people living inside the structure because it absorbed the oxygen first. This is a reminder that there are mineral components to symbiosis. Symbiosis isn't only about living entities—it includes non-living components, such as architecture. The architects of Biosphere 2 got it wrong.

Commensalism, which means messmates, is a great term for understanding of symbiosis. Who is co-feeding? Who's feeding on whom? Lichen is a core example of symbiosis as it was initially thought to be its own species, only to later be revealed as two organisms—one algal and one fungal—living as messmates, co-feeders, and commensals. The fungus produces an architectural substrate—the thallus—which holds up the algae, as algae itself has no such structure. The fungus also extracts minerals from rocks and shares them with the algae, while the algae contributes energy through photosynthesis.

Lichen only appear in harsh environments. Algae would rather be somewhere in the ocean, and fungi would rather be in moist humus. But in conditions of deprivation, they find each other and make a life together.

So much in symbiosis research isn't understood. Lead researchers still do not understand the full symbioses in a single drop of ocean water. They know that the drop contains *Prochlorococcus*, which was only discovered in the 1990s after advancements in microscopes. It's a type of picoplankton that photosynthesizes but can't produce everything it needs to metabolize, so it relies on metabolites coming from unknown critters elsewhere.

Symbiosis offers a lens to consider ecosystemic relationships. This stuff is wild and can get your brain to operate in really useful and innovative ways.

MG I'd like to respond to Caroline's comment on isolation in scientific research and how scientists place objects of study outside of relationships. I was trained in science, and I always had to be positioned as an outside observer in the work I was doing with plants. This tension is why I wanted to expand beyond the field.

Now in my artistic work, I have the capacity to be in a relationship with what I'm studying—I can interact with and acknowledge my presence in the research. While I'm still this entity observing from afar or above, every time I feed a culture or a plant that I'm caring for, I'm creating an input for it and I'm receiving an output in return. Now, my work feels more like a conversation—I'm a mediator rather than just an observer of isolated materials. It's important that we try to better understand this connection.

Even in a sterile room, you're in the presence of unseen organisms. When you enter a room, you bring your own organisms with you. My work aims to work against isolationism and to center relationships. I also like bringing in the idea of symbiosis, especially in my recent work with kombucha. Bacterial Cellulose Sheets, 206

What can we learn from working with living matter? One key thing I've learned is that we tend to want control over things. With living matter, you really don't have control. You can maintain certain conditions, but the results will still likely be unexpected. There is always a sense of surprise when collaborating with living matter, which creates new relationships.

AC Maru, what you touched upon in terms of control or lack thereof is really fascinating. In design fields, especially architecture, there's a long-standing idea of predetermined outcomes. Architects tend to design outcomes with an expectation that matter will behave in a certain way and remain static for as long as possible.

Through engaging living matter, the biggest shift in my design work is that I'm no longer determining outcomes, designing conditions, or controlling results. Instead, I'm guiding, pushing, and pulling—allowing my relationship with the material to influence and become the work. The final product comes out of these dialogues. Many questions important to my work have emerged from things I initially labeled as failures.

There's also been a major shift in design thinking focused on the longevity of materials. We're in an era where our materials are more durable while our buildings have shorter lifespans. We demolish buildings at an amazing rate. We have this idea of fast architecture, like fast fashion, where everything is changing very quickly. There is a constant desire for consumption—not just of the physical but also of ideas—we don't linger very much nowadays. This raises questions about whether materials actually need to last as long as we design them to. Pushing back against this idea of things having to remain static, I'm interested in concepts of growth and decay. Can architecture become food for later on? How can a material's change be useful? Algae-laden Hydrogels, 210

This is a refreshing conversation for designers. For the longest time we were focused on mitigating the accumulation of waste, accepting it as permanent. Now we're thinking about regenerating landscapes and how to feed all aspects of a process. There's something beautiful about the closed loop of these ecologies, including all the symbiotes and bacteria in our bodies and in the environment.

CAJ Returning to Maru's theme of relation—I've been mentoring an architecture student who is studying corn. The word "corn" is an English import and originally meant "seed." I advised the student to return to the word "maize" and find the relational context because in most Indigenous epistemologies, these relations come with a lot of work and responsibility.

There are vestiges of these relations in certain symbiosis theories. When these biological theories started being published in the late nineteenth century, anarchist Peter Kropotkin was right on it and recognized this as a good political lesson. It's all about living. It's all about relations. For the symbiosis roundtable conversation, I wanted to bring together Native American thinkers, primary amongst them Robin Wall Kimmerer, who has a PhD in botany and is trying to honor Indigenous ways of thinking and relating through her work as a botanist. So kin in biological science is considered really reductively in Mendelian genetics—that's super different than the kind of relations that Maru and Assia are talking about. The more we can enlarge, we see relations as our responsibility, especially concerning biomaterials as they serve as a new form of extractivism. For example, how much can we extract out of mycelia? Do the mushrooms have rights? Have you listened to mushrooms? Where do they want to grow?

These questions of relation and responsibility need to come together—as they have in your practices. Consider the difference in English between gardening and agriculture. Agriculture is a distant institutional practice managed by various invisible agents—gardening is like, you might have to go out and decide what a weed is to you? Or who are you hoping will grow? So… gardening creates the conditions as a matter of coaxing.

Returning to *Symbionts*, our exhibition timetable was not ours or the museum's, but the mycelia's. I am always interested in allowing for a small amount of rogue agency—like thinking you've eliminated something, but there might be a spore on the edge of the thing that is just waiting for the right conditions to thrive. While a gallery doesn't want to allow for these uncontrollable possibilities—that little rogue element always intrigues me.

Claire Pentecost has created a brilliant soil-erg economic system that she wants us all to convert to. The soil ingots couldn't leave Germany because soil cannot be exported between ecosystems. However, when she paints with the soil—it's pigment—it's epistemically converted to an art material and assumed to be inert, and so nobody goes into the work to investigate if symbionts came in with the dirt painting.

This notion of responsibility, while open to unpredictable events, also needs to come with the tenderness of concern for consequences. We must make sure to have a precautionary principle because many humans' attempts to relate to the environment have led to unintentional consequences, benefiting one organism at the expense of another.

This is a great segue into another question, not only the subjects of your research, but also yourselves as types of institutional subjects—whether an artist working under various institutional models like residency programs and gallery spaces, or as a researcher within a specific university setting. How do you navigate the kinds of outputs demanded from you when working within these institutions?

Following Caroline's reflection on ethical codifications and relationships that you push up against in your work, can you share or reflect on some of these experiences? In particular, we'd love to hear more about whether you've developed a code of ethics or formal or informal guidelines, and how they guide you.

AC Much of the research that is currently of high interest at academic institutions is historically rooted in extractivism—the capitalist emphasis on how much can be taken for profit. How does it compare to existing resources? Is it better? Is it scalable? How does this very small petri dish research translate into architecture and how does it become building?

A symptom of being within an architecture department is that there is a lot of conversation and focus on scaling and mass production. Everything these days is prefabricated with an emphasis on speed and efficiency, which is very different from the idea of spending a hundred years fabricating or building something bit by bit. This creates ethical and theoretical tension in academia—why are we doing something and where do we draw the line and why?

My thinking on bioethics emerged from working in a lab and initially, having come from a design field with no background in science, I had very reductive ideas about living organisms. Genes are exciting to architects because they are like LEGO blocks that can be moved around, pulled apart, and stacked together. However, after spending time in a lab you realize complexities. For instance, you can engineer a gene into bacteria, but within maybe 9,000 generations, one of these bacteria may decide it doesn't need the gene and spit it out of its gene sequence, and then influence this change across the rest of the colony.

Starting to understand that social structure shifted my thinking and my interest toward what these organisms, designed over millions of years, can do that we haven't figured out yet. We haven't explored a a vast portion of the work we do. There are species that we haven't identified. There are species that we're eradicating every day that we don't even know about. During this conversation, we've lost an incredible amount of diversity out there. Conversations with scientists influenced a shift in my focus, and I started to gain a contemporary scientific understanding of these organisms.

I didn't expect the high level of responsibility and care that is present within a laboratory setting. I began working in a marine science lab, where my colleagues were working with single-celled or very simple organisms. Their rhetoric was evocative of animism, and it was considerate. There was huge concern about the terms and potential impacts of their actions, especially when a species was engineered to serve a purpose or when releasing things into the natural ecosystem. This started to inform my ethics research. How do we shift into this mode of thinking in contemporary society?

MG These questions about ethics and our responsibilities towards our subjects bring a lot to mind. People generally get very excited about advancements in science and technology, such as human and genome modifications and CRISPR—these are very trendy topics, but I worry because we tend to view these advancements as inherently positive without considering their potential consequences and what or who is behind and in control of them.

I try to work with protocols. I try to consider myself in the space and time of the other organisms, plants, microbes, and other small ecosystems that I'm engaging and creating with. I draw from ideas and principles required for scientific research—like having systems, objectives, parameters, and the proper tools.

At the same time, I've developed what I think of as arts protocols, which come from personal thoughts, advocacy, and promotion for reduce, reuse, recycle, and other sustainable practices. These protocols have evolved for me and every time I am creating a new work, I'm also considering protocols of encounters such as relate, remember, respect, rethink, reconcile, restore, remediate, and regenerate.

Returning to what Caroline was saying about the art world and museum spaces, working in a traditional "white cube" gallery presents a lot of difficulties when working with living matter like bacteria. But of course, the gallery is always working with bacteria. The idea of bringing in contamination can be frightening and stressful, not just in terms of living matter, but other materials as well. For example, I work with soil contaminated with lead. I am often met with resistance when bringing this contaminated soil into spaces because it's considered dangerous, yet we'll see ceramic objects with beautiful finishing that is lead-based. There's a duality in how we treat materials in the arts.

When creating this type of work, we have to recognize it as a living process—it's not just something that you create and that is the end of it. One of my first experiences thinking about this, both as an artist and scientist, was at the beginning of my career when I was at the National Center of Genetic Resources in Mexico. They have collections of genetic material from endemic species in Mexico, including plants, animals, and bacteria, and in my work there, I was interacting with this bacteria that grows in soil where corn is cultivated. It was fascinating work, particularly when examining the relationships within the soil that made the seed and then created this corn. I worked with a scientist, doing traditional work like testing, making mistakes, and making studies and drawings. The work would end by putting the thing we had created into a machine that would make sure the organisms did not get out. It was this process of creating a life cycle of maybe a one-hour duration, a very small span to be alive, and then closing the loop of the lifecycle in the machine so it did not contaminate the entire space.

Assia, I keep returning to what you were saying about the longevity of materials, both those meant to last longer and longer as well as biomaterials, which are meant to decay.

Why do you think that there is such a desire for materials to last longer? How does this fit into your practice?

AC There is a desire within the industry to continuously match the standards that we've set for ourselves, and to align with our definitions of comfort, of space, and of enclosure. We have very high standards for comfort nowadays. Even compared to our previous generations, what we consider to be a base level of comfort—it's actually extreme comfort. We're so out of touch with the elements—there is no human relation.

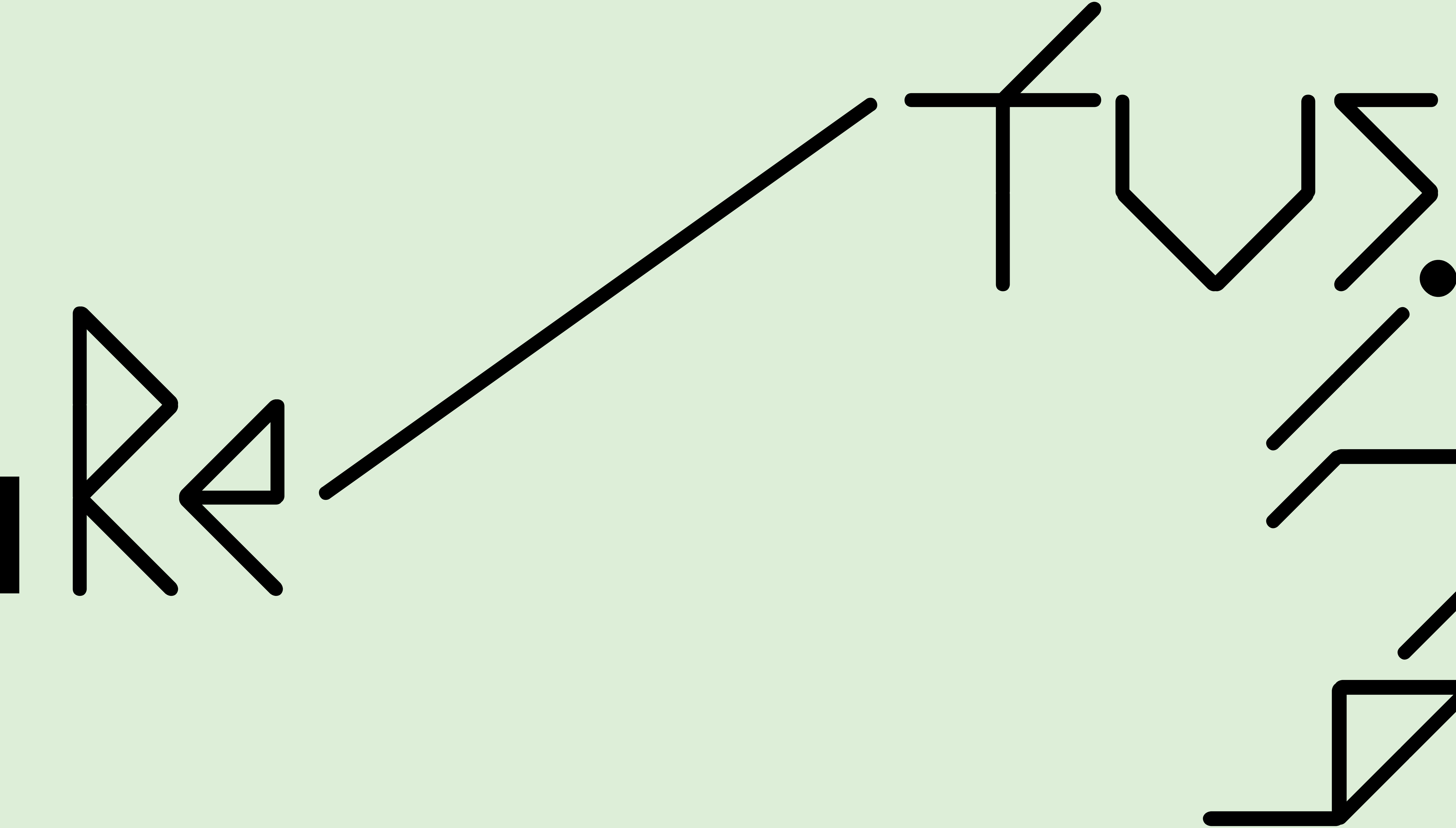
Humans have a preoccupation with and expectation of being here forever. There's this false notion that, even if we mess up this planet, we're just going to move on to the next one, and this is reflected in the desire for permanence in design and materials to show remnants of this age—obviously very capitalist objectives. I find a lot of value in disrupting these modes of thinking.

It's ironic, this need for things to last hundreds and thousands of years, when as a species, we've only existed for such a short amount of time, and we're just going to phase out these materials in 20 years anyways because we'll need to buy and produce more.

CAJ I know we have to end, so I'll offer a quick parting thought about language: "domus," and the concept of domestication—like domesticating humans by settling them among a variety of plants. Materials are the products of co-evolution and domestication. "Domus" is an interesting concept because it understands nature as something having been produced as other than us. This also connects us back to our earlier discussion on relation because if you switch "domus" for the word "life" or the word "home"—these are the spaces that we want to be in.

These alternate readings of language remind us to think expansively about that reciprocity of material as an agent.

A lot of this focus on verbs reflects the idea that it's not only humans, but also materials, who are verbing, and across all categories.



Re-fusing: An Introduction

In his 1860 study of technical and tectonic arts *Der Stil*, Gottfried Semper recounts French naturalist Alcide d'Orbigny's travels to what we now call Bolivia, where d'Orbigny unearthed "a seam of coal containing potsherds, two meters above the brine of Pampas clay, in an eight-meter layer of washed-up sand."[1] D'Orbigny argued that these artifacts of Indigenous Moxo culture evidenced the existence of people and art before a great, perhaps Biblical, flood. These deductions constitute an early idea of chronostratigraphy, which understands the earth as a record of geologic time containing sited traces of extractive and productive activities.

In 2014, the *Geological Society of America* announced the appearance of "plastiglomerate," a stone made of plastic fused to rock, that is expected to produce a new Anthropocenic marker horizon in the planet's sedimentary record.[2] In 2019, global consumption of extracted matter exceeded 92 billion tons; the United States is responsible for 30% of this, with 60% diverted to the US construction industry. And the UN's 2022 Global Status Report for Buildings and Construction noted that the 2021 construction sector produced record high CO_2 emissions.[3]

Fusing practices take disparate material—such as loose dust and clay, aggregate, and fossil fuels—and mass-process them into less perishable products like ceramics, concrete, and plastic. Conventional fusing operations source materials from extractive landscapes and transport them across large distances to factories before arriving transformed at the construction site. Fusing produces and exacerbates the CO_2 statistics above.

Re-fusing gathers design practices that respond to environmental crises by rejecting standardized conventions and testing alternate material collection and solidification methods with a focus on place. Collecting and solidifying matter is not new; sedimentary processes, in which minerals settle and over time become rock, have always taken place due to the earth's centrifugal force. *Re-fusing* practices intervene by accelerating, localizing, or otherwise experimenting with material-fusing methods in human contexts. Anupama Kundoo describes her works with earthen clay bricks as a practice that *takes* time, investing knowledge and value in local labor economies, rather than *saving* time through reliance mass-producing corporations. Fired-on-site Masonry, 214 Kundoo's office localizes material-making in unexpected ways: her *Voluntariat Homes* project was built from unfired clay and filled with clay building materials and housewares. Setting the project on fire hardened the homes and the contents, making them impermeable to other elements.

BC architects, Assemble, and Atelier LUMA treated Lot 8, a renovation of an old train depot in Arles, France, as a full-scale bioregional experiment in how to incorporate local materials, such as rice, straw, salt, stone quarry dust, and sunflower stems, limiting the project's extractive extents to a 45-mile radius. Bioregional Building Products, 218 This

approach required close collaboration with local contractors, who, unable to work with specification sheets of standard materials, co-learned how to work with new material mixtures alongside the designers. Post Rock, a Michigan-based research team, similarly approaches their local context as a resource, harvesting waste plastics from Detroit-region car manufacturers and transforming them into upcycled plastic panels. Waste Plastic Cladding, 216 The collected plastics undergo processes of filtering, melting, molding, compaction, and re-solidifying—a contemporary acceleration of geologic lithification. Post Rock's approach to sourcing accepts the saturation of "synthetic" materials in our late-capitalist landscape, expanding what it looks like to work regionally.

The 3D printing projects of Rael San Fratello similarly encounter our contemporary context by working with local materials. The office iterates recipes of bioregional materials—salt, local wood, forest fire ash, mud—before feeding mixtures through customized 3D printers, some as large as a truck trailer. Printed Adobe, 220 In their 3D-printed adobe structures, we see a pairing of ancient and new technologies. While building with mud, an Indigenous craft across many geographies, has been a prevalent technique for millennia, it is rarely an approved method in the US. Ben Loescher advocates for adobe's entry intro local and International Building Code, noting that its resistance to standardization and status as "free dirt" outside of profit-driven procurement systems make it difficult to apply through conventional methods of material specification. Re-fusing Conversation, 136

Finally, Mae-Ling Lokko explores how humans have nurtured fire as a partner in processing and transforming matter into material. Mae-Ling Lokko, 124 From fire's capacity to draw lime from limestone, to the low heat of organisms that digest plastics, Lokko illustrates how fire, as a connective force, contributes to a circular view of our engagements with the things that surround us. Lokko also writes about the Aboriginal concept of "country"—entwined relationships between human and non-human, animate and in-animate elements of an ecology. As microplastics flow through our bodies and plastiglomerate washes up on our shores, this worldview urges us to consider what is around us as both resource and relation. What kinds of planetary connections do our material engagements express and sustain? How do we navigate our stratum, our geological present, and what will we leave behind?

1 Gottfried Semper, *Style in the Technical and Tectonic Arts; or, Practical Aesthetics*, trans. Harry Francis Mallgrave (Los Angeles: Getty Research Institute, 2007), 564.

2 See Patricia L. Corcoran, Charles J. Moore, and Kelly Jazvac, "An anthropogenic marker horizon in the future rock record," *Geological Society of America Today* 24, no. 6 (2014): 4–8, https://doi.org/10.1130/GSAT-G198A.1.

3 See Sharm El Sheikh, "CO_2 emissions from buildings and construction hit new high, leaving sector off track to decarbonize by 2050: UN," UN Environment Programme (November 9, 2022), https://www.unep.org/news-and-stories/press-release/co2-emissions-buildings-and-construction-hit-new-high-leaving-sector.

The Yard

Rael San Fratello
La Florida, CO, USA

Printed Adobe, 220

Photography by Tag Christof



RE-FUSING IN THE YARD

The building site for Rael San Fratello's printed adobe experiments is situated on a vast parcel of land in the San Luis Valley, a region that straddles Colorado and New Mexico. It is a place where Mexico, the United States, and present-day Native American territories intersect, and where Ron Rael's family has resided for seven generations. Earthen matter forms the surface of this land, or as soil scientists have anthropomorphically termed it, the "skin of the earth." This land, or skin, or soil, is the source material for many of Rael San Fratello's experiments, which blend ancient and contemporary technologies, coupling adobe construction with robotic manufacturing. On this building site, a recipe mixture of soil, clay, and straw is fused together to produce architectural variations in structure, textures, and tool paths. Over time, exposure to weather returns the buildings to soil and to land.

Re-fusing: On Heat Regimes and Material Circularity

Mae-Ling Lokko

The primordial elements are four in number: air, fire, earth, and water; and that it is from their coherence to one another under the molding power of nature that the qualities of things are produced according to different classes. And, in fact, we see only that all which comes to birth is produced by them, but also that nothing can be nourished without their influence, nor grow, nor be preserved.

—Vitruvius[1]

Lime Kilns by Night by Joseph Mallord William Turner. Source: Yale Center for British Art, Paul Mellon Collection. Public Domain.

Changing Primordial Elements in the Twenty-First Century

Ever since the harnessing of fire, humans have nurtured an independence from the sun that has been wielded as a foundational force in shaping architecture. Fire has been grounded in the architecture discipline through its historic symbolic value and enduring contemporary use, from its warming of the domestic hearth to its veracious appetite for oxidizing fuels that drive energy infrastructures.[2] Relative to the three other primordial elements as defined by Vitruvius—air, water, and earth—the capacity to use fire as an ally has vastly extended human power over materials and landscapes. Humans stand idly by as fire fights against material resistance, either rapidly accelerating or delaying the return of materials to the other three elements through complete or partial acts of combustion. On agricultural fields, fire has long-since aided the return of crop residues to air and earth, while in pyrolysis chambers, fire is used

1 Vitruvius, *Ten Books on Architecture*, trans Morgan Hickey Morgan (Cambridge, MA: Harvard University Press, 1914), 225.

2 Luis Fernández-Galiano, *Fire and Memory: On Architecture and Energy* (Cambridge, MA: Massachusetts Institute of Technology, 2000).

to combust biomass, rubber, and plastic materials into carbon-rich solids and gases.[3]

Fire is also used as a powerful partner in strengthening organic and inorganic materials, paving the way to lodge impurities, binders, and admixtures into homogenous material matrices and generating recombinant materials. In a common use as a disciplinary agent, fire is wielded in metal tempering to toughen metals by heating them to temperatures just below their melting points before cooling. Applied in collaboration with controlled pressure, fire is a reliable accomplice in thermally compressing weakened or aging materials into mechanically superior products. Today, to compensate for the design of short-sighted material lifespans and large volumes of solid waste, fire has become essential in fusing and re-fusing everything from single-use plastics and discarded textiles to agricultural biomass residues to generate longer-life products. However, given fire's varying capacity to substantially exacerbate or remediate environmental toxicity alongside circular material practices, broader ecological frameworks are urgently needed to recalibrate cultures of fire around material production, transformation, and degradation.

Material transformation and circularity across ancient human cultures are often embedded in cosmological belief systems that are both constituted and driven by air, water, earth, and fire. Clay pottery in the ancient Mayan worldview, for instance, represents the metabolic interaction of clay from the aquatic underworld with the upperworld element of fire.[4] In the Aboriginal Australian cosmic concept of "country," material components of animate bodies like flora and fauna are inseparable from the inanimate components of the ecology through which fire, in concert with the other elements, facilitates exchange.[5] And in the Western tradition, both the human body and building materials are underpinned by these elemental relationships, and are not dissimilar from the material vitality of soil.[6]

According to Vitruvius: "Those [materials] which contain a larger proportion of air, are soft; of water, are tough from the moisture; of earth, hard; and of fire, more brittle."[7] Accordingly, "earthy" juices like blood, milk, sweat, urine, and tears course through the human body. Continuously heat-tempered around 37°C by its internal core organs and muscles, healthy human blood contains known compositional ratios of water, oxygen, and solid "earthy" components like red and white blood cells and platelets. Just as human health is directly impacted by the maintenance of primordial ratios, the health of soil is dependent on a continuous exchange and storage of fluids: "earthy" materials dissolved in water form a spectrum of juices that flow and saturate the internal air cavities within soil.

Two millennia after Vitruvius's treatise, the qualitative shift brought about by the climatic and geological impacts associated with the Anthropocene in the very nature of these four elements offers new predicaments on what constitutes the identity and health of twenty-first-century materials and what the role of humans should be in the responsible management and remediation of material ecologies. Not only has the fear of fire's strength and spread in built environments fueled low biodiversity across building materials, but it has also, with the use of flame retardants, driven the increased pollution of indoor air.[8]

Furthermore, since the first commercial production of synthetic plastic in 1907, 200 million metric tons of plastic waste have entered our ocean, with an estimated eleven million metric tons added every year.[9] Given that 70 percent of our planet's surface is oceanic water, which has the capacity to break down, mix, and transport materials across long distances, significant quantities of plastics that have entered the ocean are now distributed widely across the planet. This vast range of small particles less than five millimeters in diameter is gradually reconstituting everything from the chemical composition of sand, to atmospheric quality, and to the human gut microbiome.[10]

While plastics dominate the surface and interior of our oceans, 80 percent of ocean waste offloading has reconstituted the bottoms of rivers and canals with toxic industrial waste accumulation.[11] The impact of changing ocean floor topography and chemistry continues to be associated with coastal erosion, bioaccumulative pollution, and water composition changes that underpin the health of marine ecosystems and coastal habitats.[12] This has resulted in the rising frequency of new primordial phenomena including oceanic "dead zones" with reduced oxygen levels or highly toxic "red tide" algal

Casting Metal, Tomb of Rekhmire by Nina de Garis Davies. Source: MET Collection. Public Domain.

3 Cody J. Wrasman, A. Nolan Wilson, Ofei D. Mante, et al, "Catalytic pyrolysis as a platform technology for supporting the circular carbon economy," *Nature Catalysis* 6 (July 2023), 563–573.

4 Patrice Bonnafoux, "Waters, droughts, and early Classic Maya worldviews," in *Ecology, Power, and Religion in Maya Landscapes 23*, ed. Bodil Liljefors Persson (Munich: Verlag Anton Saurwein), 31–48.

5 Bill Gammage and Bruce Pascoe, *Country: Future Fire, Future Farming*. (Melbourne: Thames & Hudson Australia, 2021), 1.

6 Gammage and Pascoe, 241.

7 Gammage and Pascoe, 46.

8 Uhde, E., & Salthammer, T., "Impact of reaction products from building materials and furnishings on indoor air quality—a review of recent advances in indoor chemistry," *Atmospheric Environment 41* (2007): 3111–3128.

9 Jeffrey L. Meikle, *American plastic: a cultural history* (New Jersey: Rutgers University Press, 1995), 40; and Katsiaryna Pabortsava and Richard S. Lampitt, "High concentrations of plastic hidden beneath the surface of the Atlantic Ocean," *Nature Communications* 11 (2020): 4073.

10 Fackelmann, G., & Sommer, S., "Microplastics and the gut microbiome: how chronically exposed species may suffer from gut dysbiosis," *Marine Pollution Bulletin 143* (2019): 193–203.

11 Gross, M. G., "Effects of waste disposal operations in estuaries and the coastal ocean," *Annual Review of Earth and Planetary Sciences* 6 (1978): 127–143.

12 Gross, *Annual Review of Earth and Planetary Sciences*.

Channel Country in Queensland, Australia, showing vegetation (bright red), mud and sediments in the Georgina and Diamantina Rivers (cyan) and desert, bare soil, and rocks (green). Source: European Space Agency.

blooms.[15] With the infiltration of synthetic and chemical components into interconnected material cycles, there are shrinking opportunities to escape such new natures.

Given the reality of such material ecologies, today's existing hierarchy of design strategies for material transformation cascading from reuse, recycling, landfill, and incineration require new paradigms of design, entrepreneurship, and economic investment. Akin to recycling, coursing the veins of the material reuse paradigm lies a contradictory goal of designing materials to last forever, which typically requires the use of energy intensive, rare, or toxic processes that often compromise healthy, trophic activity within material ecosystems. Material design propositions that do not engage the reality of the surrounding material muck are at best short-sighted and, at worst, a privileged side-step.

Microplastics appear almost indistinguishable from soil mineral components in the Azores. Source: Peter Charaf, Creative Commons License.

It is in this spirit of "muck," including material surplus, contamination, microparticles, and leachates, that fire exists as a force to redress material displacement across twenty-first-century ecologies. Whereas the use of fire as a universal solvent has underpinned the successful control and scaling of inorganic material production, this has had disastrous impacts when transposed onto forestry and agricultural landscapes, diverse material families, and climates, leading to rising levels of combustion byproducts as well as ecological pollution. To address this, the careful spatialization, timing, and intensity of fire regimes within an ecological framework offers key opportunities for anticipating fire's spread and engaging its capacity to drive material regeneration. Similar to the art of metal tempering, the strategic use of fire in the production of fused and re-fused materials is critical in ensuring such processes do not merely compound negative life-cycle impacts, in lieu of short-term performance gains.

15 Bennett, N. J., Alava, J. J., Ferguson, C. E., Blythe, J., Morgera, E., Boyd, D., & Côté, I. M., "Environmental (in)justice in the Anthropocene ocean," *Marine Policy* 147 (January 2023): 105383.

Fire as a Universal Solvent

From a material processing perspective, Vitruvius's description of fire bears close kinship to today's contemporary use of fire as a leveling force in material processing. For Vitruvius, fire is represented as a "universal solvent" capable of dissolving the natural resistance of a material with its fiery force and weakening the material to a state of surrender. Under firing processes, chemicals bonds of varying strengths between elemental components in different materials are broken and rapidly forced to initially react with oxygen. In his examination of lime production, for instance, limestone's capacity to bond with sand can only be achieved after it has undergone heating until exhaustion. This process of relentless heating lays bare limestone's pores for oxidation processes, rendering it ready to react with water to form a new material.[14] In the burning of coal and inorganic minerals like limestone, oxidation occurs at temperatures of between 1300–1500°C, while for organic biomass this occurs between 200–350°C.

Paradoxically, along this temperature spectrum, social perceptions of safety and control appear to improve alongside higher temperatures. Fear of fire within human habitats are largely dominated by lower band temperatures around 200°C, at which the ignition of fibrous and thatch materials occurs and spreads quickly in open air. As temperatures rise to 500–700°C, around which common wood biomass like pine or oak burn, human anxiety around fire dissipates and becomes more closely associated with thermal and psychological comfort. At different scales and cultures, human gathering around the domestic hearth and communal bonfire socializes domestic rituals of cooking, marriage, socialization, rest, and death.[15]

At the next, higher temperature band of 800–1100°C, fire has been creatively wielded as a tool for mineral and metal fusion. Not only has the traditional firing of earth bricks relied on the fusion of lime and sand at these temperatures, but firing has been used to overcome scarce material properties. For example, given the rarity of color blue in nature, ancient Egyptians and Romans developed a process that leveraged fire to heat sand, the flower of natron, and copper to temperatures of 800–900°C in a ceramic vessel. At such temperatures, all three inorganic materials are forced "to mix in each other's sweat and relinquish their peculiar qualities," yielding rarefied, permanent blue pigments.[16]

On a material scale, social perceptions of fire in relation to human safety have directly driven material design and integration logics. Enforced by material fire performance standards and fire safety building codes, toxic chemical additives are integrated into the material matrix or surfaces of almost all materials today to prevent and inhibit the spread of fire. Despite growing awareness of

14 Vitruvius, *Ten Books on Architecture*, 46.

15 Fernández-Galiano, *Fire and memory: On Architecture and Energy*, 8–11.

16 Vitruvius, *Ten Books on Architecture*, 218–219.

their persistent toxicity, the continued growth of a 7.6-billion-dollar global market around fire retardants reflects a deeply seated fear of material vulnerability to heat and weathering.[17] In contrast to the increasing volumes of materials, often laden with toxic chemicals, that eventually make their way onto landfills or oceans, fire can be a counter force in curbing material pollution. Here, the thermal re-fusion of mixed material streams to generate higher material density products shifts the pattern and scale of pollutant pathways, prolonging the participation of such materials in the market economy. However, given that the interaction of "fused" material products with primordial elements can negatively impact indoor and outdoor environmental quality, new spatialization paradigms, integration design, and servicing models for such composite material systems are key to driving non-toxic decomposition and ongoing maintenance of the built fabric.

Fire Farming

In contrast to the use of fire as a ravenous force for heat-tempering and re-fusing materials, writer Bruce Pascoe describes the Aboriginal conceptualization of fire as a regenerative agent.[18] Similar to the low-grade fire burning regimes practiced by Native Americans, Aboriginal Australians developed practices of "cool burning" systems to drive the abundance of domesticated flora and fauna. Through the quick and partial burning of relatively small amounts of strategically spaced biomass and underbrush at specific times, coupled with an understanding of prevailing wind and dew patterns to control their direction and spread, the risk of wildfire was eliminated. Knowledge around the timing of fires was heavily informed by an intimate familiarity with soils, memory of the last cool burn within the context of plant life cycles, and the observation of weather patterns. Fire planning regimes were also critically preceded by sharing schedules and knowledge among neighbors.[19]

Across country, knowledge around the present fertility of soil also informed where cool-burning was done. Cool burns were performed on fertile, productive soils, while unproductive soils were left to remain as forestlands. Within agriculturally productive patches of land, the regenerative impacts of cool burning both forced seeds to crack open and stimulated preserved biomass roots and moisture below ground. Cool fires gave such lands a "kiss of life." Here, the spurt of shorter, nutritious "sweet feed" attracts fauna like cattle and kangaroos and also becomes the site for human hunting practices.[20]

In the context of today's catastrophic wildfires, new platforms and avenues are emerging to overcome barriers to cool fire regimes including farm fences, land use, property boundaries, as well as the

Fire-making by an Aboriginal man in New South Wales. Source: Wellcome Collection. Creative Commons 4.40.

17 Global Flame Retardant 2023-2032 Market Report, https://market.us/report/flame-retardant-market/.

18 Gammage and Pascoe, *Country: Future Fire, Future Farming*.

19 Bruce Pascoe, *Dark Emu Black Seeds: Agriculture or Accident?* (Broome, Austrailia: Magabala Books, 2015), 227–228.

20 Bliege Bird, R., Codding, B. F., Kauhanen, P. G., & Bird, D. W. "Aboriginal hunting buffers climate-driven fire-size variability in Australia's spinifex grasslands," *Proceedings of the National Academy of Sciences 109, no.* 26 (2012), 10287–10292.

complex politics of land ownership and air quality.[21] Beyond fire management, the knowledge systems around plant cycles intrinsic to cultural burning practices are part of deeply interwoven agricultural and architectural traditions intrinsic to vernacular building practices. Literacy around soil and plant life cycles plays a critical role in determining how biogenic material harvesting for material applications can be designed and timed to promote the health and resiliency of soil ecosystems.[22] Such approaches extend the capacity of material designers and specifiers to stimulate "market-pull" demands that support species abundance and enhance biodiversity.

Flameless Fire

Whereas fire relies on the burning of a fuel in the presence of oxygen, heat relies on the transfer of thermal energy between material media. On a global scale, differences in the heat content of primordial elements drive local to planetary climatic and geologic patterns that shape microclimatic flows across built habitats. At the building scale, heat exchange between primordial elements in contact with the building's material systems determines the thermal conditions of indoor spaces and their surrounding outdoor ecologies. Across diverse climates, long-standing building practices have used primordial elements—water, earth, air—in concert with mineral and organic materials to serve as thermal storage within building walls and roofs to absorb, slow down, and control the release of heat.[23]

At the material production scale, relatively low-grade heat (just under 180°C) in combination with pressure helps create a broad category of materials made from reconstituted wood, agricultural or forestry residues, plastics, textiles, and diverse aggregates. Typically preceded by shredding, milling, and pulverization, such approaches require a mechanical reduction of material into constituents, and partial destruction of structural bonds. A higher degree of erasure of the material's former identity and the capacity to improve standardized "bits," including small chips, particles, fiber lengths, pellets, and fluff, often corresponds positively with the quality of the new material and their near-term market demand. In addition to the labor and energy requirements for mechanical degradation, material "bits" then require glues to piece them back together in an anonymous, packed configuration. Due to the negative impacts of synthetic glue concentrates in factory settings, as well as the persistent off-gassing of harmful chemicals from the large surface areas of thermally pressed materials, the toxicity and chemical behavior of glues under heat is critical to consider in the design of healthy indoor environments.

21 Leah Penniman, *Farming While Black: Soul Fire Farm's Practical Guide to Liberation on the Land* (Vermont: Chelsea Green Publishing, 2018). David W Crowder, Tobin D. Northfield, Richard Gomulkiewicz, and William E. Snyder, "Conserving and promoting evenness: organic farming and fire-based wildland management as case studies," *Ecology 93*, no. 9 (2012), 2001–2007.

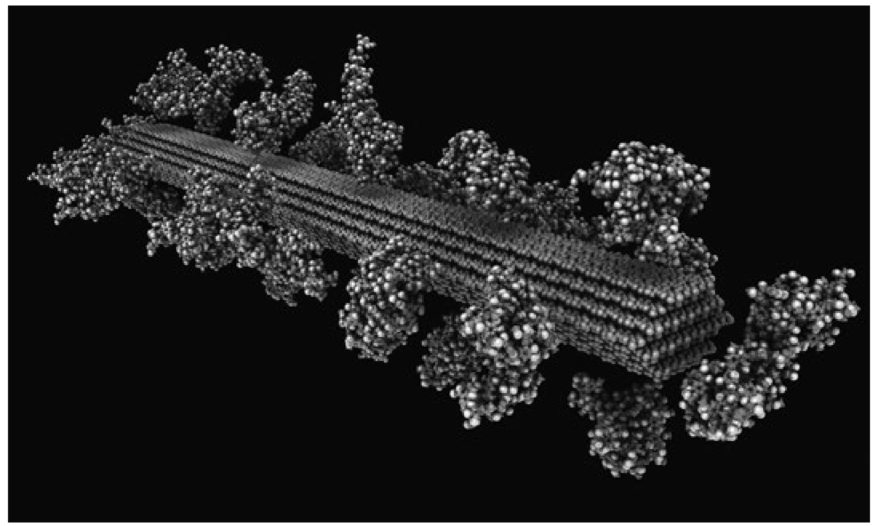
22 Peter Osborne, Núria Aquilué, Marco Mina, and Kiel Moe, Michael Jemtrud, and Christian Messier, "A trait-based approach to both forestry and timber building can synchronise forest harvest and resilience," *PNAS Nexus 2*, no 8. (2023).

23 Mona Azarbayjani, and David Jacob Thaddeus, "High Comfort-Low Impact: Integration of Thermal Mass in Pursuit of Designing Sustainable Buildings," in *Achieving Building Comfort by Natural Means*, ed. Ali Sayigh (Cham, Switzerland: Springer International Publishing, 2022), 47–97.

Since the late nineteenth century, glues used in wood and reconstituted wood industries have been dominated by toxic, petroleum-based urea-formaldehyde, isocyanate, and other formaldehyde-based adhesive binders that are responsible for the off-gassing of volatile organic chemicals into indoor environments.[24] Furthermore, across an increasing myriad of material recombination substrates—wood-biomass, mixed plastic, wood-plastic, plastic-mineral aggregate, or bioplastics—increasing percentages of glue can be used to compensate for substrate variability, non-standardization, and mechanical strength. From a circularity perspective, the consequent impregnation of toxic glues into pressed material products merely delays and multiplies problems of toxicity and non-biodegradability. The use of synthetic glues in such materials often results in toxic, higher thermal-pressing conditions and disposal practices which drive up embodied carbon emissions associated with the manufacturing, maintenance, and degradation of materials. In rethinking tradeoffs in short-term material performance gains for long-term ecological toxicity, new criteria around end-of-life processes should be centered in material design practices.

The use of natural binders within plant materials as an alternative to synthetic glues offers a promising approach to curbing high material carbon footprints and long-term toxicity. Termed "binderless boards," the thermal pressing of biomass residues leverages a relatively gentle intensity of heat to force the internal bonding of naturally abundant and non-toxic glues. In plant cell walls, a complex conglomeration of polymers known as lignin molecules wrap around the prized cellulose sugar molecules like packing peanuts. Responsible for reinforcing, binding, and connecting plant walls, lignin plays a critical role in strengthening

24 Steve Brown, "Occurrence of Volatile Organic Compounds in Indoor Air," in *Organic Indoor Air Pollutants: Occurrence-Measurement-Evaluation*, ed. Tunga Salthammer, (Weinheim, Germany: Wiley-VCH Verlag, 2009) 170–184 and Jensen, Lilli Kirkeskov, Annelise Larsen, Lars Mølhave, Mogens Kragh Hansen, and Bodil Knudsen, "Health Evaluation of Volatile Organic Compound (VOC) Emissions from Wood and Wood-Based Materials," *Archives of Environmental Health 56* no. 5, 419-432.



Lignin molecules wrapped around straight chains of sugar molecules. Source: Oak Ridge National Laboratory. Creative Commons Attribution 2.0.

plant architectures. Found in abundance in plant barks, skins, husks, peels, stems, and barks, lignin is part of a plant's defense system that protects cells from harmful molecules, invasive organisms, and climatic conditions. Compared to other plant protective barriers, which are typically composed of less than 30 percent lignin, the husk of mature coconut contains over 40 percent lignin.[25]

When thermal pressing a wide range of plant skins and material, lignin binders soften and dry out as temperatures approach 140°C and a chemical cross-linking occurs.[26] This irreversible condensation of lignin bonds formed under low-grade heat replaces the need for synthetic glues in plant-based thermally-pressed composites.[27] In contrast to synthetic glues, if left uncoated, pressed biocomposite materials remain "breathable" maintaining unique porous matrices that improve their capacity to hold moisture, cool via evaporation.[28]

Biological Fires

Relative to material transformations stemming from heat and firing, biological digestion offers another frontier for material recycling. In collaboration with other species, fungi have historically served as the ubiquitous agent for both decomposing dead matter and enabling living matter to embark on new conquests within uncharted material environments.[29] In agriculture, the presence of fungal activity enhances all forms of plant activity, including their photosynthetic systems, through maintenance of the soil structure beneath it, and rapid decomposition of dead plant matter through enzymatic activity.[30] Mycelium—the vegetative part of fungi—has the capacity to digest a vast variety of materials, including plastics, and is an effective biomass-to-biocomposite material technology. Feeding on tightly bound lignin and cellulose components of organic matter, mycelium can metabolize a diverse arrange of materials ranging from hydrocarbons and carbohydrate chains to generate resilient chitin-bound green building materials at recommended room temperatures of 18–24°C. Effectively "growing" materials under low-energy conditions, these chitin molecules can be use in non-toxic bioproducts.

Like fungi, fire and heat may be important allies in directly sequestering, transforming, and maintaining twenty-first-century material muck. As one of nature's best chemists, fungi has both deconstructed and renewed our material worlds while heat has continuously shaped and conditioned it. Stemming from fire's pervasive capacity to force reactions between material constituents, decisions on when to use fire, to what intensity, for how long, in what spaces, and on which materials, if at all, fire has become an intrinsic force to engage when prescribing and

25 Van Dam, J. E., van den Oever, M. J., Teunissen, W., Keijsers, E. R., & Peralta, A. G., "Process for production of high density/high performance binderless boards from whole coconut husk: Part 1: Lignin as intrinsic thermosetting binder resin," *Industrial Crops and Products* 19 no. 3 (2004), 207–216.

26 Van Dam, J. E., van den Oever, M. J., & Keijsers, E. R., "Production process for high density high performance binderless boards from whole coconut husk," *Industrial crops and Products* 20, no. 1 (2004), 97–101.

27 J. Xu et al., "Manufacture and properties of low-density binderless particleboard from kenaf core," *Journal of Wood Science* 50 (2004): 62–67.; R. Hashim et al., "Characterization of raw materials and manufactured binderless particleboard from oil palm biomass," *Materials & Design* 32, no. 1 (2011): 246–254; Van Dam et al., "Production process for high density high performance binderless boards," 2004.

28 Mae-Ling Lokko and Alexandra Rempel, "Intrinsic Evaporative Cooling with Natural Ventilation and Shading for Adaptive Thermal Comfort in Tropical Buildings," 7th International Building Physics Conference, Syracuse, NY, 2018.

29 Stefan Rensing, "Great moments in evolution: the conquest of land by plants," *Current opinion in plant biology* 42 (2018): 50–51; Xiaoliang Fu et al., "Fungal succession during mammalian cadaver decomposition and potential forensic implications," *Nature. Scientific reports* 9, no. 1 (2019): 2–5

30 Geoffrey M. Gadd, "Mycotransformation of organic and inorganic substrates," *Mycologist* 18, no. 2 (2004): 60–70.

Mycelium growing on the panicle of a plant. Source: Creative Commons 4.0.

spatializing material systems within the built environment. In opposition to contemporary energy and material paradigms which rely disproportionately on active mechanical heating and sealed environments to condition a space over its lifetime, a direct link between the design of healthy materials with thermodynamic regimes is central to accelerating non-toxic circular material practices.

Laurens Bekemans, Ben Loescher, Meredith Miller, and Virginia San Fratello on Re-fusing

What follows is a conversation on the material act of Re-fusing with Laurens Bekemans, Ben Loescher, Meredith Miller, and Virginia San Fratello, and the *Material Acts* team. Re-fusing highlights practices that work adjacent to systems of mass extraction, instead incorporating overlooked and reclaimed materials such as earth and plastic waste into processes of aggregating and fusing.

We'll begin the conversation with the observation that, in each of your practices, there's often ingenuity and atypical approaches to sourcing material. The materials that you work with fall outside of conventional extractive and discarding cycles, or you're actively seeking to intervene in extractive procedures. What are your material sources, what led you to these spaces, and what does the work of getting material entail?

BL I'll jump in! We work with earth. It's like catch-as-catch-can, right? The material that we use to make adobe and compressed earth block is everywhere. It's underneath our feet, but, at the same time, it can be surprisingly hard to get to for practical and regulatory reasons. So we're often working around the edges, looking for opportunities—like when you're driving down the road and there's a sign that says "free dirt."

We get a lot of our clay from an aggregate mine that mostly sells gravel to CalTrans for paving and freeway repairs. The clay is thirty feet of what they call "overburden," which has no commodity value and happens to sit on top of something that's deemed super useful. So we're driving around, looking for heaps of things, calling numbers on signs, trying to make connections because there aren't traditional supply chains for the materials that we use.

VSF Sourcing local, inexpensive, and even free materials is really important to us as well. We work in the space of additive manufacturing, which tends to be really locked down by the companies that make the printing equipment and sell the proprietary materials that go into 3D printers. In the beginning, we were priced out. We were buying used equipment, buying the materials to put in the printers… thinking about the financial accessibility of materials for ourselves translated into thinking about accessibility for others. Of course, earth is ubiquitous and free and is, in many ways, a non-commodifiable material. How do we keep it that way and make it mass-consumable at the same time? Printed Adobe, 220

We also work with salt, which prints really well because it's sticky and it costs 99.9 percent less than the proprietary white materials that you put in a 3D printer. And, being in the Bay Area, it comes from right here, so I don't have to pay to ship it around the world—and that's really important in terms of thinking about the economies of construction. We also use materials in the waste stream like sawdust from the Sierra Nevada mountains, which are close by, or Chardonnay grape skins from Sonoma and Napa. These are materials that are essentially free.

We're also interested, especially with materials like earth or ash, in the historical and political conversations that can be had about material provenance. Any 3D printing with earth or ash or salt sits in a continuum, a larger and longer context of building with these materials. We're interested in that narrative, too, and understanding where we sit in a legacy that is already thousands of years old.

LB Brussels is trying to position itself within Europe as a pioneering city in terms of circular economy and circular construction. At the political level, the government is organizing and pushing legislation in such a way that incites architects to consider reuse, and alternative geo-sourced, bio-sourced materials. What's interesting, in contrast to California, is that Brussels has a set of contractors and enterprises responsible for the demolition of the city, and they bring concrete from demolition sites to recycling centers where they crush the material. These companies also excavate, for example, for the extension of the metro line and metro stations. There's a riverbed under the city that is composed of really rich clay and sand. We are connected to these companies so when we are in production for projects, we can get specific, local ingredients for compressed earth blocks, rammed-earth mixtures, and plasters.

We've managed in the past years to set up what in French is called a *filière*, a material culture around excavated earth. And now our next step is mainstreaming this, making this economically viable. Bioregional Building Products, 218

MM Hmm. I'm realizing that our practice, Post Rock, is an outlier here, in that we're not working with earth, but we're working with waste plastic. I do want to go back to something that Ben said about earth being everywhere. I would say that, unfortunately, plastic is also everywhere and is arguably becoming a geologic material. In fact, I think our initial inspiration for Post Rock was the discovery of a new geological material called plastiglomerate, which are rocks that turn up on beaches and in marine environments that are formed as waste plastics fuse with sand and seashells and other garbage, but they have all of the qualities of hardness and durability that make them, by definition, rocks. If it's hard enough to be a rock in the environment, perhaps this re-fused plastic is hard enough to be an architectural material that has value. Waste Plastic Cladding, 216

In terms of sourcing, we've recognized that here in Michigan we're at a nexus of manufacturing. There's a long history of many different kinds of extractive and industrial activities in Michigan and, particularly in Detroit, there's the auto industry. We've learned that a lot of the plastics that are used in the auto industry have similar performance requirements we would need to get a plastic product certified for use as building material. So we're thinking about our project as providing a second life for plastic waste that gets discarded in the manufacturing process of automobiles.

I wanted to follow up on another thing Ben said about regulations acting as a filter. Earth is abundant, but regulations apply a layer of information to that earth, like what can and can't be used. I'm curious to hear more about that because there's a parallel with plastics. Plastics is a huge category, but actually, there are so many different kinds of plastics that are specially engineered for very particular uses. We found this presents a lot of challenges for introducing circularity. So I'm curious to hear more about the limitations of circularity with earth.

BL Well, I think there's a cultural bias against things that are free—because if it doesn't cost anything in our peculiar cultural system, that means it has no value, right? Of course, we know that's not true. And then with earthen materials, the more that they can be graded or standardized or classified or whatever, all of a sudden they become products again, right? For example, clay may be free until it's identified as bentonite or something like that and then it can enter supply chains as a commodity.

Curiously, in the work that we do, there are a million different ways to make an adobe brick or a compressed earth block, and this is really vexing for a lot of engineers and regulatory types. One soil can make a competent brick with 11 percent clay but with a different soil, you might need 30 percent clay. Some folks can't wrap their minds around material variability, so the strategy that we've been taking is to standardize around performance rather than specific content or classification.

Defining materials by their performance characteristics allows us to adopt language that regulators and engineers are more comfortable with. I mean, the truth is that building regulations and standards production are very expensive—so for a material that doesn't cost anything, that means in a country like the United States, there's no public benefit research going into these things. You either have to adapt and co-opt the existing system or commodify the material, which as Virginia was suggesting, sort of like starts to make it less desirable as an actual material to use.

VSF I'll tell you all a story. We have a building called the *Cabin of 3D-printed Curiosities*, which is made out of some of the materials that we've developed over the years. And we were able to build this because the cities of Oakland, San Francisco, and Berkeley relaxed their building codes in response to the housing crisis. There are just not enough places for people to live. So now you can build up to 1,200 square feet on private property without a design review. We could build a tiny building made out of Chardonnay and 3D-printed sawdust and salt because we're faced with this much larger crisis around housing, and that sort of opened the door for us and possibly others to do backyard experiments. We are getting ready to do a 3D-printed earthen structure in Southern California and we need that to be engineered and approved and to meet building codes. I think we will get into a situation where we are making adobe using local clays and soils and we'll have to test them, you know, for their compressive strength to make sure that they do meet the standards required by the building code. And we've done that once before in Colorado. So, we're facing this—but again, it'll be a small experimental structure. I don't know what happens when you want to build housing, for example, or public buildings. That scale seems like an almost insurmountable hurdle to overcome, to get policy to change to allow for this type of construction to happen.

LB We're doing a few public buildings and a university campus here in Brussels. One project is a hempcrete structure, and we couldn't find a contractor who could manage to do it. In Belgium, when you're using these newer materials, it's often too expensive when calculated by contractors or too risky or uninsured, and so on. So we organized an open workshop to build the project with the public. Another example, for another project, we were working with a newly developed rammed earth using stone dust, but only two craftsmen knew how to do it, and the building was thousands of square meters large. We first had to cultivate and share knowledge with people.

We've learned that when you use locally sourced materials that are not off the shelf, your material is less of a product, it is more of a cultural network. We're challenged to set up new protocols for building and—always—to share knowledge.

VSF I want to return to your comment about insurance and risk—the United States is a very litigious country, and so considering risk is important. Do you want to take on the risk of an earthen building in an earthquake-prone context? Ben, maybe you can talk a little bit more about this, too, because you're working in this space as well.

BL It's funny because, with adobe and compressed earth block, the engineering for seismic is not tricky. They're conservative designs and ultimately, with an engineer who is familiar with these materials, it's not hard to prove the math on them. Your bricks or masonry units have known qualities that just get plugged into a model with rules of thumb and it all works out. The barrier is often cultural—it's like, "adobe—that sounds that sounds suspicious," right? So we have to adopt technical language that sounds more neutral. Let's call it "unfired clay masonry" because that's benign, and you can imagine the same sort of thing, the same sort of approach being used for other materials as well, right? I started doing this in 2006 without success for a very long time because I started at the local level trying to use so-called alternative materials. After several failures—because building departments are set up to say no—and once I started participating in national standards development and international building code, I realized it's substantially easier to just change the building code for the entire United States and have it trickle down to the jurisdiction in California we're working in than it would be to get a single building permitted in Los Angeles County.

MM Yeah, I was going to bring upscaling, too, because it sounds like everyone has mentioned thresholds at which the rules change, or at which there's more scrutiny as to what you're doing or whether the building can stand up—and that might be literally the scale of the building or it might be the typology or it might be the jurisdiction. For us, there was a split in our research several years ago. We were making more composite materials and making bigger and bigger things. We were making these hollow monolithic structures and made a column and our idea was that we'd make buildings out of this. But we realized that the scale of the problem that we're trying to engage with is so large that rather than us making these one-off weird monolithic structures, maybe we need to develop a product that could be manufactured.

Scaling up could mean not necessarily an object that could absorb more waste plastic, but producing something that would play nice with more conventional building. So that's why we've been working on rainscreen cladding. But we still set the bar maybe a little too high in that we're working on having it certified for taller buildings… I won't bore you with those details.

It's similar to what you're saying—we've scaled up and scaled down, at the same time, so that we might produce something that would actually get used in the world. We maintain dreams of doing our monolithic experiments, but right now we have a lot of support for scaling our research into a commercial product. In a way, it's a different relationship to material production and design, and it's been an interesting learning process for sure.

It's worth noting how a lot of the work of bringing new methods and materials into common use and practice is taking place in the peripheries of the field, and further that it's rather administrative labor like regulatory testing, production scaling, building code writing.

MM Yeah, I mean part of what led us to cladding as a possible application for our research is the way that IP works. Early on we developed a patent, but the patent was for the process of thermoforming waste plastic with aggregates—the configuration of the mold, the application of heating—because we couldn't patent plastic. I bet it's the same with earth, right? You can't patent earth. It exists. But maybe you can patent novel processes.

From a university research point of view, IP gives us some validity in that we have something that could be marketable. For us, as designers, we're also interested in the aesthetics of the materials and we want to control the flow of the plastic, the textures of the different aggregates that we add, etc., and so the idea of cladding made a lot of sense.

Cladding isn't structural, but it does need to withstand wind and other forces. It needs a certain degree of durability. The main thing is fire. Initially, everyone raises their eyebrows because you're basically putting petroleum on a building. But, you know, again, different plastics are engineered for certain uses and there are many plastics that have already solved this problem, so it goes back to sourcing and the question is: what forms of expertise do we need not only to engineer and understand how this will behave under fire but also to navigate the plastics industry to use the right plastics? A lot of the process right now is building up a network of consultants and advisors just so we can build the supply chain that we need.

LB I continue to think about different kinds of scaling, and want to share that the hybridity of BC architects and studies and materials emerged over time. We did our first earth project almost twelve years ago but it was more recent, as our practice started to get public projects, that we hit an economic limit, meaning the materials we wanted to use became too expensive in our Belgian context. bc studies began as a way to organize workshops for teaching and learning because there was interest in the materials we were developing. We held a workshop where volunteers helped us make over twenty thousand compressed earth blocks for a building. bc materials was then started to further research on these earth materials—and it is now our product arm that offers Brussels-based and Bruges-based materials to other architects and contractors.

With this scaling, we now have to think about production scale and placing a price on these materials. If we want to have more impact, how can we make our product accesible to the family down the road? So we started to do research. In Belgium, there's already a culture around masonry, and machines for compressing blocks are common. To lower the price of a block, you need to produce more—not like making a few blocks at a time using a hydraulic press as we would in a workshop. We would need to make millions.

We started looking at machines used by concrete factories that compress concrete blocks used for sidewalks and so on. We hacked these machines that already existed in our city to instead produce large quantities of compressed earth blocks, and simultaneously established a set of industrial agreements. We were able to rent the machines for one day a week, the factory would help us with sales, and we could offer earth-based products at half the price they would be otherwise.

BL You know, listening to you and Meredith both, it seems like a path opened up because there's an analog for the material, whether it's a facade panel of which there are lots of types, or a masonry unit that's culturally familiar: it provides a framework for people to understand what you're up to. And I guess I want to ask Virginia: do you have an analog? It seems that a lot of the work you've been doing just breaks all the rules. It's not just a bit of a misuse of a material, it's an entirely new method of assembling and it's like, oh, well, you just need to think of it.

VSF There are lots of misconceptions, like people will just have no idea how you're 3D printing. I feel if you look at a compressed earth block, you understand how it was made just by seeing it and if you look at a piece of, say, 3D-printed wood, you don't. There's a lot of mystery and confusion around the materials that we've experimented with over the years, and I guess we've tended to stay in that early phase of research, a space where we are inventing the materials at particle scale—we're doing a lot of bench testing.

We are thinking about algorithmic code as well. How does the code and the toolpath make this material perform better? How does the geometry that I'm scripting improve the programmatic qualities or the structural qualities? And more recently, we've been working in the space of developing simple robotics. So we're working with a fabricator who makes 3D printers to make a really lightweight robot arm. We haven't gotten to the point yet where we're considering policy or large-scale building or trying to meet ASTM (American Society for Testing and Materials) standards. It seems like a big hurdle to me to jump over and I'm torn. Do I just stay back here and let someone else take that on or is it a line that I really need to cross and is it time to do that?

MM It seems tools are a way to address your question, Virginia: do you need to be the one to pass the standards? It sounds like the research and figuring out of which tools work with which material composites is a huge contribution that could be built upon, and it makes me curious what your attitude is about open source or proprietary knowledge. Do you see the development of tools as something that would be available to other people to build on your research, or do you see them as staying within your practice?

VSF We published a book that has some of our recipes in it, so we've given away some material formulations, and we sell the software that we've developed for 3D printing with clay for a very, very low price. We're not making a profit off of it, it just helps us to pay to host the software in the cloud. Ronald and I are of course both professors. We teach our students how to do all of the things that we have learned ourselves. If they go and work for another architect or designer and they take the workflows they've learned to another practice, that's fine because we've taught them how to do it.

And we think a lot about tools. We've moved into the space of working with robotics, which sometimes means fabricating our own end effectors, you know, literally making our own tools. And so our thinking is beginning to shift toward making these tools open-source and placing them online for anyone to download and 3D print and put on the end of their robot arm. It all returns to a desire to lower the bar and to make things accessible in terms of material use. We have the same ethos and philosophy with materials as we do with software and tools and shared knowledge.

MM Yeah, yeah, I think that's so important.

We keep thinking back to what Laurens said earlier, about material as a network. Sharing

thoughts on access to information, production of tools, forums of collaboration, and various kinds of knowledge that get pulled into these efforts—this is a great culmination of our conversation. It is, in a way, an expanding of a network; we can all see ourselves as extensions of and resources for each other. We want to offer this reflection in closing, but also ask if any of you have final thoughts or a better way of wrapping this up.

LB We're all quite hybrid as practices, and I feel there's a human understanding of all the challenges met when you're not following a blueprint. When you're trying to find your way, you have to do things differently and spend energy in a very different way. I appreciate this culture around materials, and I really do connect to thinking about materials not as products but as networks. We are building a regional material, it's not like a concrete product that might have been produced on the other side of the world. The material relates to your human network or your geographical network.

BL Yes, the network aspect is really unique to these emerging and non-traditional materials because once something is normal and commodified, it just sort of disappears into the landscape of economic interactions and, also, into industrial secrecy. At the risk of sounding like a Marxist or something, there is some unquantifiable benefit to entering a dependency that's non-economic with with other individuals, and these materials enable that.

VSF I'll just go with what they said and also say, to be continued. It's all this ongoing work we're talking about, and it's hard to summarize because you are right in the middle of the work, it's progress in process!

Stitc hing

Stitching: An Introduction

A stitch, in both literal and metaphorical uses, brings disparate pieces together—it is a form that articulates plurality. Moreover, the stitch is a fundamental structure in the production of textiles, which, in their capacity to cover, protect, and envelop, are theorized to have enclosed our earliest dwellings.[1] As built environments evolved to express permanence, requiring walls that could bear weight, textiles were relegated to a secondary status in architecture as temporary, lightweight surfaces (like tent fly sheets) and domestic objects (like curtains, baskets, and blankets). Yet today, as the reality of an everlasting robust architecture is increasingly challenged, many contemporary practices have returned to softer, more flexible approaches to enclosure.[2]

Acts of stitching have long been accomplished by hand—whether by a solitary pair of hands, as when one darns a sock, or by a collective of hands, as when a group makes a quilt. The proximity of the stitcher to their product exemplifies what Pamela Smith calls "vernacular science," in which the hands-on act of making is crucial to forming an embodied sense of knowing. Stitching practices form and are themselves informed by social correspondences and, as Smith writes, it is through a web of making ("repeated experiences and experiments in producing tangible things") that early artisans created "generalized, replicable, and transmissible knowledge about nature."[3]

Stitching presents contemporary work situated at the confluence of distinct communities of knowing, gathered from different disciplines and geographies—bridging not only materials but also cultures of knowledge. In response to our current state of overproduction and consumption, many design practices that stitch actively work against the construction industry's tendencies to overchemicalize, vitrify, discard, and standardize. In Joar Nango and Sara Inga Utsi Bongo's *skievvar* experiments, halibut offal is washed, stretched, and sewn with reindeer sinew to yield translucent panes that can cover building apertures and filter light. Sewn Fish Stomach, 224 These materials are harvested through Indigenous Sámi hunting and fishing practices that developed over millennia to complement the ecological cycles and rhythms of Sápmi (so-called Scandinavia). Nango's design office operates out of a van that he drives to the fjord shore, to Utsi Bongo's small town and elsewhere, in a modern-day adaptation of the traditionally nomadic Sámi way of life, which migrated with and as part of the reindeer herds they cared for. The Seashore, 150 Such attunement of material practice to one's stewardship of place invokes Ariella Aïsha Azoulay's unlearning of imperialism, which attends to "the violence that presumes people and worlds as raw material, as always already imperial resources."[4]

The research practices of Felecia Davis and Lola Ben-Alon call attention to the histories and knowledge of laborers who've been exploited or made invisible. Davis's explorations of machine-knitting

techniques to produce architecture-scale panels of dreadlocked Black human hair represent, as she states, a nexus of thinking around surplus waste and the dependence of textile economies, to this day, upon slave labor. Knit Dreadlocks, 226 *Stitching* Conversation, 176 Competing value and economic systems converge in this work as human matter becomes architectural material through a reconfiguring of mass-production technologies to reproduce processes that typically occur in salons and living rooms. Davis's research asks us how our bodies may figure as material in building—while pointing out that marginalized bodies have always been implicated. Lola Ben-Alon's research happens in a university laboratory that she refers to as a kitchen—where bio-based and biodegradable material recipes are produced, including combinations of locally sourced, clay-rich soils with agro-waste plant fibers. Fiber-rich Earthen Textile, 228 In one vein of Ben-Alon's research, a fiber-rich soil mixture is machine-extruded while a hand-guided mold catches the fibrous earthen thread, producing a woven structure in which the mold (weft) supports the extrusion (warp). Earthen material, conventionally expected to function as masonry units in compression, is, in this framework, explored as a self-supporting yarn that holds a form in tension. At the heart of both Davis and Ben-Alon's practices are collaborations between women and machines, commonplace cyborg alliances in histories of craft and technology. While designed to reproduce domestic labor, machines—whether in a site of mass production, an academic laboratory, or a kitchen—still rely on human oversight.

What can be learned from these practices, and what possible futures do they hold? Elsa MH Mäki describes the act of stitching as an act toward repair, one that "requires a closeness to observe and thrash within broken systems." Elsa MH Mäki, 164 In writing about the visibility of a mend and the piecing together of contingent, recovered materials, Mäki argues that stitching is a practice that accepts life "inside ruins, and [makes] use of what remains." To meet our current world as one who stitches is, perhaps, to predispose oneself to seeing use in industrial scraps and other materials that lie in the wake of globalized, capitalist societies—foregoing tendencies toward "raw materials," and relocating architectural craft back into human hands.

1 For one example, see Gottfried Semper's theory of textiles in early architecture, where woven surfaces served as both ground cover and vertical enclosure. *Style in the Technical and Tectonic Arts; or, Practical Aesthetics*, trans. Harry Francis Mallgrave (Los Angeles: Getty Research Institute, 2007), 248.

2 The idea that buildings are static entities remains prevalent, but is not the case in practice: a 2004 paper published by the Brookings Institution reported that from 2004–2030, roughly 82 billion square feet—or almost a third—of existing building stock in the US will have been demolished and rebuilt. (https://www.brookings.edu/articles/toward-a-new-metropolis-the-opportunity-to-rebuild-america/). See also, Anni Alber's never-too-late prompt from 1965: "If the very nature of architecture is the grounded, the fixed, the permanent, then textiles are its very antithesis. If, however, we think of the process of weaving and compare the work involved, we will find similarities despite the vast difference in scale…textiles, so often no more than an afterthought in planning, might take a place again as a contributing thought." Anni Albers, "The Pliable Plane: Textiles in Architectures," *Perspecta* 4 (1957), 36.

3 Smith, Pamela H., Amy R. W. Meyers, and Harold J. Cook, eds. *Ways of Making and Knowing: The Material Culture of Empirical Knowledge* (New York: Bard Graduate Center, 2017), 40.

4 Ariella Aïsha Azoulay, *Potential History: Unlearning Imperialism* (Brooklyn: Verso Books, 2019), 8.

The Seashore

Joar Nango
Tromsø, Norway

Sewn Fish Stomach, 224

Photography by Joar Nango

STITCHING ON THE SEASHORE

Joar Nango's mobile practice takes him to and between numerous sites around Tromsø, the largest urban area north of the Arctic Circle. His approaches to building and working within this northern landscape are evolutions of Sámi tradition and generational practices in reindeer herding. To produce his *skievvar* experiments in using fish stomach to produce architectural screens, halibut offal is rinsed, split, and dried before it's sewn together as a textile sheet using reindeer sinew. These steps involve collaborators who contribute expertise across various crafts, including Sara Inga Utsi Bongo, whose doctoral and artistic work in textile-making advances *duodji*, or Sámi crafting methods. Materials are sourced and much of these activities happen outdoors, aided by utilitarian objects such as plastic tubs, wooden boards and frames, nylon rope, and foldable sawhorses—tools that endure and travel well.

Stitching: Future Fabrication and Traditions of Reuse

Elsa MH Mäki

When you begin stitching, it is rarely with new material ("new" meaning purpose-made, industrial-grade, fully sealed, and never-before-touched). Stitching is a hybrid practice; it brings different things together. Most familiar in the context of handicrafts, repairing clothes, or accumulating short segments of video into a longer narrative, the verb "to stitch" applies to the built environment as well. In cohering craft knowledge and environmental context around the scale of the human hand, stitching challenges routine thinking on the origin stories of designed places and things. In other words, stitching can destabilize the supposedly linear relationship between nature and the city in favor of more complicated and interesting shapes. Stitching frees makers and materials to form new entanglements rich with possibility for inter- and anti-disciplinary thinking. Eliding a traditional definition of rawness that is "found" in "nature," stitching instead makes room to investigate the many positions that one can take on the contemporary built environment: from *ennui* at genericized luxury, to academic interrogations of style and cultural power, to frustration or optimism at attempts to "go green." Thinking through the act of stitching, it becomes easier to disregard the limited operative categories of

Patchwork wrapping cloth (jogakbo) by an unknown maker. Creative Commons CC0 1.0 Universal Public Domain Dedication.

architectural business as usual (style, type, sector, use-case), and instead to consider building more holistically, from supply chains, labor, craft, and heritage to its ruin, resurrection, and endurance. To stitch is to spend less time on what could possibly be designed and built, and more on what's already here, how it was made, and who will take care of it.

Broader systems that deliver buildings under capitalism are often compared to one another through parameters like weight, strength, standardization, code compliance, or the minimum possible wage. For instance, the qualities of mass timber tend to be juxtaposed to the bulk of systems and trades accustomed to non-alternative materials,[1] or the efficacy of continued reliance on concrete put in balance with the impending scarcity of its preferred sand.[2] None of these metrics for decision-making can account, however, for the whole lives of buildings, or for all the kinds of building that take place in the world today, or for the building systems that might soon take precedence. In response to these more systemic concerns, some designers today step back to interrogate supply, while others accept the conventional chain in order to tweak small details and then repeat them many times over. Some are credentialed and solution-oriented within existing markets, while others remain suspicious of solutionist design. Fundamental and urgent acts of repair, however, require a closeness to observe and thrash within broken systems, and to stay—by choice, or by lack of choice—with the trouble.[3]

With its manual connotations, the act of stitching seems equally applicable to material attached by hand and needle as to landscapes patchworked by larger devices.[4] Consider, for instance, wildlife corridors, where small pockets of retained and restored biome are planned close enough together for species to hop between them, avoiding the concrete and asphalt fabric of semi-urban sprawl. Stretching disciplinary boundaries or swapping methods from different professions further pollinates an understanding of nature and material as cyclic, full of exchange. Stitching tells me to treat materials as processes rather than products, and enables me to ask childlike questions that might actually take us somewhere: Why is the usual way of doing things still being done? How did this get here, and what would it be doing if they had left it alone? Who was involved in making this, and what do they think of the work? Will this still be here when I'm gone?

1 Jim Robbins, "As Mass Timber Takes off, How Green Is This New Building Material?" *Yale Environment 360*, April 9, 2019, https://e360.yale.edu/features/as-mass-timber-takes-off-how-green-is-this-new-building-material. The lexicon of sustainability has a habit of sorting materials that enter architectural territory into two camps: "alternative"—possibly good?—or "standard"—bad, but well-understood. This sorting seems to embed a logic of replacement, of this for that, without considering the complex net of interactions and transformations that make anything into a discrete object with a designed purpose. I hope that poking fun at alternative and non-alternative materials helps us think about more than swapping out current practices for nominally adjusted ones.

2 See Arnaud Vander Velpen et al., "Sand and Sustainability: 10 Strategic Recommendations to Avert a Crisis," UN Environment Program Report (Nairobi, Kenya: United Nations, April 22, 2022), https://www.unep.org/resources/report/sand-and-sustainability-10-strategic-recommendations-avert-crisis. These considerations for concrete and carbon even arise in discussions regarding the cycles of war and rebuilding in Gaza. Natasha Aruri, Balakrishnan Rajagopal, and Brad Samuels, "Architecture, Planning, and International Law: On Domicide" (The Architectural League of New York, May 23, 2024).

3 Donna J. Haraway, *Staying with the Trouble: Making Kin in the Chthulucene* (Durham, NC: Duke University Press, 2016).

4 Stitching also brings to mind international tribal efforts to restore bison habitat across a huge swath of the Great Plains divided by the US-Canada border. Damage done to this ecosystem through genocidal Indian Wars-era policies, including targeted bison extermination, rail infrastructure, and unsustainable farming practices, are slowly receding in favor of land management grounded in Indigenous knowledge and stewardship. See Dan Joling, "Alaska Prepares for Wood Bison Return after a Century," *CBC News*, March 20, 2015, https://www.cbc.ca/news/canada/north/alaska-prepares-for-wood-bison-return-after-a-century-1.3003762.

5 This is not dissimilar to a cotton gin or a musket, the two bellwethers of industrial standardization as a result of their reliance on interchangeable parts.

6 Kristina Rapacki, "Interview with Kader Attia," *The Architectural Review* (February 2024), 77.

7 People have been doing this forever and everywhere. Consider stitched gourds, kintsugi, and embroidered manuscripts, among many other practices of returning damaged objects to use. See Gaetano Speranza, ed., *Objets Blessés : La Réparation En Afrique* (Paris: Musée du Quai Branly, 2007).See also Kader Attia, Maria Hlavajova, and Wietske Maas, eds., *Fragments of Repair* (Cambridge, MA: MIT Press, 2025, forthcoming).

8 Rapacki, "Interview with Kader Attia," 78–79.

A repaired calabash from Kenya by an unknown maker, stitched with plant fiber. Held in Cambridge University's Museum of Archaeology and Anthropology since 1950. Collected by Louis Leakey, MAA 1950.562. Photo: Lucie Carreau, https://www.museums.cam.ac.uk/blog/2022/05/27/scars-and-stitches-repairs-in-african-collections.

Design and Repair

Modernity and its legacies of settler-colonial building have accelerated genericism: a centrally designed and peripherally dispatched sameness. Buildings are now made as object-assemblies with standardized parts and, in the US for instance, everyone groans at another 5-over-1 with the same four cladding materials wrapping blandly over steel and engineered lumber.[5] An architecture made of leftovers, scraps, waste—material assemblages stitched together—diverges from this standard. That is to say: entropy frustrates standardization. The wear for which all buildings are destined—through weather, war, redlining and redevelopment, retrofitting, maintenance, and the marks of human and animal life—is assiduously externalized from "new" building and the investments that fuel it. The moment a building is inhabited, it is worn and will always require repair. Artist Kader Attia says that, in Western modernity, "repairing something is to erase the injury," sacrificing the depth and continuity of care evident in scars for a perpetual newness that is unblemished and apolitical.[6] Among a growing number of today's architectural thinkers and teachers, Attia posits "repair" as the conceptual and practical foundation for an anticolonial ethic.[7] Within an exhausted capitalism, old and new visions for the world are taking root. According to Attia:

> Everyone is talking about repair today because it resonates with a need to stare at the blind spots of our societies. The environmental catastrophe we are living in is an intersection with so many topics that carry the weight of modernity. So, you can talk about systemic racism, patriarchal structures, classism, and so on: all these blind spots that have made modernity a delusional project. Thinking about repair has become a tool for revealing the ways in which we are all still living in the colonial laboratory … What often happens today is that we theorize a lot and then grasp for examples that incarnate what we are arguing. It is like the idea of care. We talk about care and then we organize dinners. We should organize the dinner first and get in touch with the materiality of that tangible experience.[8]

First, organize the dinner. But until we are together in the same room, gather up these ideas—repair, care, energy, extraction, citation, reciprocity—and dump them in a pile. Rather than sorting them by discipline, time period, or reference, let them jumble. Digest them together. Consider a repaired calabash from Kenya, stitched with plant fiber: the hollowed fruit, dried up and woody, is a superlative vessel. Sometimes its skin is richly decorated;

sometimes left plain. Before it cracked, it could carry water or milk a long way. After breaking, it was neither waste nor useless. Mending it, the maker made no effort to hide the cracks. Instead, they repeated a large, elegant stitch back and forth along the rifts, and kept the calabash. The museum that collected it valued the same object for reasons similar and dissimilar, and they kept it too.

Even new material cut against a pattern-piece holds traces, and stitching invests an object with the residue of its rhythm and creation from miscellaneous parts. These contingencies have been a feature of global building practices since time immemorial. Think of how people describe the roughness of plaster or the grain of wood as *warmth*. Think of Inca dry-fitting techniques for stone cities high in the Andes, an art form no Western architect has managed to repeat.[9] Conversely, drywall, for instance, lacks precious endurance. Thin and pliant, it is easily tacked to a lumber frame with a nail gun, its joints smoothed out by skilled laborers working quickly to save their bosses' boss' client's money. Materials designed to require the minimum possible labor—to go up quickly—also come down quickly. Punched through a few times, the drywall can be patched with mesh and putty, but if introduced to water, it will stain and sag. This is not a material designed to withstand life, but to change apace of related, externalized values like style or real estate. The warm roughness that accompanies things made and mended by hand is more challenging to a regime of industrial progress that depends upon standardization.[10] This is not to say that slow building is always or inherently more ethical than quick; or that mass-engineered building systems do not offer lovable benefits. Instead, we should consider the accumulation of both ways of working in a patchwork built environment and ask bigger questions about how values shape livelihoods over time.[11]

Designers and scientists who approach contingent materials and leftover sites are presented with a distinct set of challenges by their counterparts working with more standardized, new construction. Materials are often conditioned by multiple processes, some of which are deemed "natural" and others a result of ("unnatural"?) human intervention. Some materials could be described as offcuts—scraps—while others are laced with the consequences of refinement, often heavy metals left behind in mines, pits, and factory grounds.[12] Scraps are rarely valued on par with "new" material unless they are first cycled back through similar industrial processes with new energy applied. There is no longer a single origin story—if there ever was one—but many, and some of these originary processes have consistently been toxic to humans and other living things.[13] To stitch things together, architects often take stock, creating an inventory of odd parts and offcuts to be assembled anew. In their Ashen Cabin project, for instance, HANNAH,

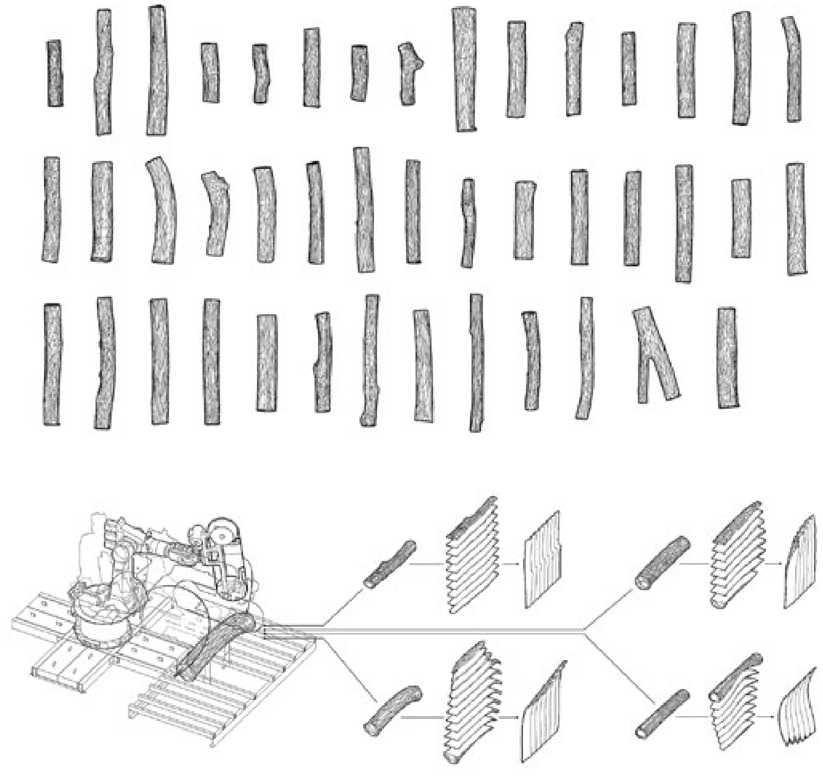
9 For super technical further reading, see Jaime Castro, Luis E. Vallejo, and Nicolas Estrada, "Mechanical Analysis of the Dry Stone Walls Built by the Incas," *The European Physical Journal Conferences* 140, no. 06012 (2017). For work deeply interested in approaching this practice from contemporary conditions within the architectural field, see Brandon Clifford and Wes McGee, "Cyclopean Cannibalism: A Method for Recycling Rubble," in *ACADIA 2018: On Imprecision and Infidelity*, Proceedings of the 38th Annual Conference of the Association for Computer Aided Design in Architecture (Mexico City, October 18–20, 2018), 404–413.

10 Charlotte Malterre-Barthes describes the technologies that produce complete environments, like BIM software, as facilitating "an anti-contextual production of space." Charlotte Malterre-Barthes, "The Devil Is in the Details: 'Who Is It That the Earth Belongs To?'" in *Non-Extractive Architecture: On Designing without Depletion*, ed. Space Caviar, vol. 1 (Berlin: Sternberg Press, 2021), 95.

11 For instance, I am thinking with Melanija Grozdanoska, "Ma maison cherche-t-elle à me tuer?" Centre Canadien d'Architecture (CCA), May 2024, https://www.cca.qc.ca/fr/articles/issues/32/pour-votre-securite/94839/ma-maison-cherche-t-elle-a-me-tuer?

12 Elsa MH Mäki, "Building Backward: Archaeology of a Queer Built Future" (Cambridge, Harvard Graduate School of Design, 2022), Harvard DASH, https://hollis.harvard.edu/permalink/f/1mdq505/TN_cdi_harvard_dspace_oai_dash_harvard_edu_1_37375320.

13 For further reading, see Tracy Brynne Voyles, *Wastelanding: Legacies of Uranium Mining in Navajo Country* (Minneapolis: University of Minnesota Press, 2015). See also: Isabelle Kirkham-Lewitt, Tizziana Baldenebro, Lauren Leving, Joanna Joseph, eds., *Sketches on Everlasting Plastics* (New York: Columbia Books on Architecture and the City, 2024).



Digital model of Ashen Cabin's scanned lumber array. Source: *ArchDaily*.

founded by Leslie Lok and Sasa Zivkovic, parametrically mills ash trees into human-sized slabs of cabin cladding. The ashes, cut down to limit the continental march of invasive insects, display the burrowing scars of the environmentally entangled process that turned them from trees (perhaps destined to be standardized, dimensional lumber) into waste material, now diverted into building.[14] Similarly, in Circularity Park, Gramazio Kohler Research assembles a large wall-pile from stones that had been scattered on site by scanning and digitally modeling each fragment, and then instructing robots to assemble the stones in an optimized order.[15] These materials are what Katie MacDonald, Kyle Schumann, and Jonas Hauptman from After Architecture call "standardless," a term—and a design ethos—that "emphasizes the natural transformation of a raw material during the fabrication process ... [and] the fruits of imprecision" borne out of novel digital fabrication.[16]

These architects describe their practices as being liberated, to some degree, from standardization through the use of digital fabrication technology, which frees them to use industrial leftovers directly and often on the same site where the waste was produced. It allows them to be somewhat agnostic to the materials available, thus distinguishing their approach from "recycling." Within this context, "developments in on-site robotic building methods offer the opportunity to leverage context-specific, locally sourced or

14 Pintos, "3D Printing and Robotic Construction."

15 "Circularity Park, Oberglatt, Eberhard AG, 2021-2022," ETH University research group projects (blog), 2022, https://gramaziokohler.arch.ethz.ch/web/e/projekte/442.html .

16 Katie MacDonald, Kyle Schumann, and Jonas Hauptman, "Digital Fabrication of Standardless Materials," in *ACADIA 2019: Ubiquity and Autonomy*, Proceedings of the 39th Annual Conference of the Association for Computer Aided Design in Architecture (Austin, TX, October 21–26, 2019), 3.

17 MacDonald, Schumann, and Hauptman, "Digital Fabrication of Standardless Materials."

18 MacDonald, Schumann, and Hauptman, "Digital Fabrication of Standardless Materials," 3.

upcycled materials that are inexpensive, abundant, and low in embodied energy."[17] These practices belong to what MacDonald, Schuman, and Hauptman call a "middle ground between designer and material," a murky and enticing overlap among material quirkiness, tool-driven form, and stylistic tradition.[18] This approach ascribes abundance to waste, which is an important proposition for building in the twenty-first century, but also one familiar to centuries prior. It also allows one to question the externalization and internalization (embodiment) of carbon in building processes. While they make use of waste in place of new material, the computing machines, their fuel, and the orientation of a site toward daily energy consumption continue to invest a place in vast networks that demand mining and fossil fuel extraction.[19] Can we then think of robotic assembly as a *reparative* practice, or as *harm reduction*? Are these two ideas even compatible? In either case, it's fun to think of huge robots and regular-sized architects trying to learn from multiple Indigenous construction techniques some 500 years later.

19 As Malterre-Barthes writes, "The production process of these high-technology machines drives extractivism perhaps as much as 'classic' construction materials do. But the material impact of data is rarely recognized or subjected to accountability, even though substantial infrastructures is required, such as electrical power, fiber networks, air-based cooling systems, and hard-drive disks, are all dependent on extractive processes." Malterre-Barthes, "The Devil Is in the Details," 95.

Mending Sampler (Germany); wool, cotton, and linen embroidery on cotton and wool foundation; H x W: 47 x 46cm (18 1/2 x 18 1/8 in.); Bequest of Gertrude M. Oppenheimer; 1981-28-318.

Feminist Labor and Endurance

Wall graphic for Felecia Davis's *Textural Threshold Hair Salon: Dreadlock*, demonstrating the hair textures evaluated by Umar Riaz Muhammad et al.'s database. *Data Wall Hair Texture Collage*, 2023, *Textural Threshold: Dreadlock*, 18th Venice Biennale of Architecture. Digital collage by Aysan Jafazadeh.

Conventional construction tends to set waves of skilled workers and their tools against instructions that were drafted and negotiated by professional workers (architects, engineers) in distant offices. After passing these waves over a given site until the project receives a stamp of approval, the finished product is left to its own(er's) devices. In alternate lab- and studio-based visions of future construction, computational mediation animates the relationship between designer and designed structure. This relationship is made simultaneously closer and more distant than today's conventions allow by rehearsing the design precisely in digital form, then enacting it in a tangible place as an object or, increasingly, as a process that carries itself out cyclically. Open-source design goes even further, following an ethic of the early internet by refusing to gatekeep or codify the status of "maker." The interpersonal rigor of this approach distinguishes it from normal product-generating design—and especially from practices that actively conceal their source material, such as large language models proliferating under the banner of Artificial Intelligence—reaching instead toward the practical generosity of long craft traditions that are handed down among makers. This ethic is evident in stitch-based works that utilize LilyPad, an open-source sewable electronics kit designed by Leah Buechley, or kobakant.at, an open repository of e-textile projects and ideas by Mika Satomi and Hannah Perner-Wilson. Meticulously and publicly citing work, especially giving credit to the labor of women and young academics, is itself a feminist ethical practice.[20] Stitching is an act of consensual knowledge production and voluntary, unpaywalled knowledge-sharing.

20 Anooradha Iyer Siddiqi elaborated on the practice of citation in her International Womxn's Week Keynote Address at Harvard GSD, March 7, 2023.

Citing the open-source tools her lab uses, Felecia Davis emphasizes that the invisible pool of digital and analog transmission in which we all swim “needs more attention to construct a life-valuing future.”[21]

Winding through air, around existing buildings, and through complicated urban conditions, tensile structures are often imagined and sometimes deployed as gentle editors of the city.[22] Contingent design and construction practices recognize that most buildings standing in the year 2050 have already been built, so primary attention must now be to their alteration and stewardship rather than their invention on supposed virgin ground.[23] While this disciplinary shift in mindset might inspire designers to move beyond the capitalistic myth of infinite growth, they would still need to contend with disaster. Destructive weather, war, and other malign events of sufficient scale have always reformatted what and how people build, and climate change is accelerating the uneven clearance of built communities. Under current building regimes, disaster is often an investment opportunity, one that reasserts or even accelerates unsustainable building-as-usual for short-term rewards. [24] Moments of rupture flood with potential. Countering these highly externalized systems in favor of building practices that help people root themselves resiliently in place fundamentally requires architects and designers to work with, not against, entropy. This is where disparate ways of working—repairing gourds, digitally modeling waste material, configuring wildlife corridors, deploying weaver drones, making a quilt together—fit as an alliance of mixed methods under the mantle of stitching as a material act. It is also a junction at which grassroots activism and citizen science have long been working. Take, for instance, the nonprofit Matters of Trust, based in San Francisco since 1998. Their “Hair Matters” program aims to create a network of waste-hair collection and felting centers by 2030. Extant centers collect and “recycle hair, fur, wool, fleece from salons, groomers, ranches and individuals,” felting them into absorptive bales and mats that soak spilled oil from waterways.[25] This work is both reparative in nature and explicitly a form of stitching in action, reminiscent of what Sámi artist and architect Joar Nango calls “nomadic thinking”:

> You see every object or every material around you as a potential problem-solving material, which really explodes the idea of the commodity and the consumer mentality. It’s a way of seeing objects and materials as something else, as something more, and giving them more value, or giving them some kind of a philosophical value.[26]

This approach to design might be called a “dissonant optimism,” but what takes place while the reparative act of stitching is done? Long, slow, sometimes mindless work carried out by experienced hands tends to make room for conversation. The gossip, the wisdom, the midwinter stories, the advice passing between generations: all this happens while a tool works its way deftly between the edges of different things. Familiar to Indigenous societies and close-knit communities anywhere, the social intimacy of these acts also resonates in the digital. Felecia Davis says that her *Textural Threshold Salon: Dreadlock* project was “about those spaces that use biodata, in this case hair, to permit or restrict access.”[27] Davis defines all thresholds as physical delineations of more ephemeral values, with *Dreadlock* illustrating the “intersection of the two via electromagnetic resonance.”[28] Davis invites viewers to study the social attachments and preconceptions woven into braids and locs from the outside. She restages the salon chair—an intimate space for handwork—as an exhibition/lab framed by an algorithm trained to parse viewers by hair texture alone. Davis also discusses the challenge of finding open databases that include Black hair textures in the first place.[29] By presenting oneself at biometric thresholds contrary to the black-box assumptions through which a database reads the world, one becomes a *trickster*, at once seen and unseen.

Making and thinking with textiles—particularly computational textiles that are imbued with conductive yarn, sensors, and other means to make them highly responsive to their environments—enables scientific research to “leapfrog” into another space, where posture and physical memory are honored as the utility of designed objects and systems. This wisdom has been situated within a “domestic sphere” since industrialization, and has been a current in feminist histories pushing outward to this day. Davis’s repertoire of computational textiles argues that these materials so closely associated with clothing, insulating, and signifying the human body inherently hold and respond to emotion, and that architectural textiles create fundamentally emotional spaces.[30] Embedding responsive technologies in this intimate material can both illustrate and heal these associations in social space. The dialects of architecture, engineering, construction, tech, and design are, in contrast, rarified and full of jargon. These professional languages hew to an apolitical tone that is service-oriented to match the twentieth-century business structures in which they operate, channeling wealth and energy. Until recently, these languages struggled to describe emotional bodies at all, much as they still struggle to take seriously anyone but the archetypal lone genius (read: male, white, moneyed). But vocabulary and culture change together.

What happens when care and repair are hollowed of their politics? When repair, following Attia’s reasoning, is driven to erase,

21 Felecia Davis, “Soft Systems: Crafting an Architecture” (lecture, Penn State University, PA, November 6, 2023).

22 For an extremely literal take on this notion, see Benedict Hobson, “Drones Can ‘Weave Structures in Space in Just a Few Minutes,’” *Dezeen*, March 4, 2015, https://www.dezeen.com/2015/03/04/movie-drones-architecture-weave-tensile-structures-ammar-mirjan-gramazio-kohler-research.

23 The often-referenced but rarely cited statistic that somewhere between two-thirds and eighty percent of existing buildings will remain in use in 2050 appears in reports by sustainability consultants and nonprofits like the UK’s Climate Change Council, 3Keel, the Canadian Climate Institute, as well as McKinsey & Company. I have not found an original source for statistics of this type; rather, they seem to be a newly formed common understanding for energy and construction policy recommendations since 2019. Gemma Holmes et al., “UK Housing: Fit for the Future?,”*Committee on Climate Change* (2019); Rob Kilgour et al., “Global Retrofit Index: An Assessment of the Performance of G20 Countries to Reduce Emissions from Buildings,” 3Keel (November 2023), https://www.kingspangroup.com/en/sustainability/product-sustainability/global-retrofit-index; Pierre Verrière, “The Future Passes through Old Buildings,” Canadian Climate Institute, May 25, 2020, https://climateinstitute.ca/the-future-passes-through-old-buildings; Stephen J. Naimoli, “Decarbonizing the Built Environment Brief,” Center for Strategic and International Studies, November 30, 2020, https://www.csis.org/analysis/climate-solutions-series-decarbonizing-built-environment; Jose Luis Blanco et al., “Call for Action: Seizing the Decarbonization Opportunity in Construction,” McKinsey and Company (New York, NY, 2021); and so forth.

24 As the war in Ukraine is financed by development dollars, see reports: “The World Bank and Ukraine: Laying the Groundwork for Reconstruction in the Midst of War” and Frédéric Mousseau and Eve Devillers, “War and Theft: The Takeover of Ukraine’s Agricultural Land” (The Oakland Institute, 2023), or, as developer proposals for razed Palestinian lands pop up in the bombs’ wake, see social media posts by Israeli developer Harei (or Harey) Zahav in November-December 2023 that pasted luxury residential architecture renderings over rubble in Gaza, Palestine, and a recent article on the developer’s West Bank projects: Hagar Shezaf, “The Fall and Rise of Israel’s First Ultra-Orthodox Settlement,” *Haaretz*, August 28, 2022. Wholesale residential demolition through bombing and road-making in Palestine and Ukraine, for instance, were thoroughly discussed at a virtual event hosted by the Architectural League in May 2024. Aruri, Rajagopal, and Samuels, “Architecture, Planning, and International Law.”

25 “Hair Matters (Formerly Clean Wave) Program,” Matters of Trust (blog), https://matteroftrust.org/clean-wave-program/.

26 Nango continues: “I’m trying to work with this attitude to incorporate the connection between context and the agency of the object. I’m trying to not separate them or pull them apart—that’s what the architects always do, for some reason. Like, very often designer architecture considers nomadism as something placeless, or something that’s traveling between airports or coffee shops. But for me, nomadism is the exact opposite.” Mimi Zeiger, “Joar Nango on Indigenous Architectures and Slippery Identities,” *PIN-UP*, https://archive.pinupmagazine.org/articles/interview-mimi-zeiger-joar-sami-architecture-joar-nango.

27 Felecia Davis, *Textural Threshold Hair Salon: Dreadlock*. See also: Kate Nelson, “How This Designer Is Using Black Hair to Inspire the Architecture World,” *Architectural Digest*, February 2, 2023, https://www.architecturaldigest.com/story/felecia-davis-hair-salon-project.

28 Davis, “Soft Systems: Crafting an Architecture.”

29 Umar Riaz Muhammad et al., “Hair Detection, Segmentation, and Hairstyle Classification in the Wild,” *Image and Vision Computing* 71 (2018): 25-37; Davis, “Soft Systems: Crafting an Architecture.”

30 Elizabeth Evitts Dickinson, “Buildings Made of Wool and Fungus? Meet the Textile Expert Who’s Making It Happen,” *Washington Post Magazine*, November 15, 2022, https://www.washingtonpost.com/magazine/2022/11/15/felecia-davis-textiles-pennsylvania-state-university/.

instead of returning places and things to life?[31] Davis asks a similar question with the *Fabricating Networks Quilt*, a community-building archival project for Pittsburgh's historic Hill District: "when does the repair push people out of their neighborhoods?"[32] With archival photos printed onto cloth and collaged with conductive copper fabric, the quilt literally embeds an audio narrative of each photo's story into its respective square, assembling a document of the district that asserts a right to belong through the memories and associations of its residents. The quilt complicates the division of analog and digital, and presents algorithmic thinking as a fundamentally human act, layering generational techniques accordingly. It also calls to mind Basma Ghalayini's introduction to *Palestine +100: Stories from a Century After the Nakba*:

Felecia Davis, Mona Mirzaie, and Taylor Hufnagle, sample of *Fabricating Networks Quilt*, fabricated for the 2021 MoMA exhibition *Reconstructions*. Many of the photos featured are from the Charles "Teenie" Harris Archive at the Carnegie Museum of Art.

> Four generations on, any Palestinian child can tell you all about their great-grandfather's back garden in Haifa, Yaffa, or Majdal. They can tell you about their great-grandmother's kitchen, the patterns on her plates, and the colours of the embroidery on her pillows ...This child has never been to any of those places, of course, but so long as they keep the memory of them alive, then, should they ever get to go back, it would be as if they had never left; they could pick up exactly where their great-grandparents left off. Indeed, wherever Palestinian refugees are in the world, one thing unites them: their undoubted belief in their right to return.[33]

You can remember a life through chapters of hair; through skin-stitched milestones faded over years in the sun and wind; through old shirts made into the squares of a new quilt.[34] More worn still are the "whole" things put to work—nets caught on rocks, jeans torn at the knees, scraps and ends—as their outlines contain no design directive toward wholeness, but instead toward the collected destinies of parts and their absent neighbors. To stitch ragged edges together is to absorb this contingency, to embrace this irregularity as a condition of life lived. Holding both edges in your hands and slowly pulling them together over a story is a profoundly intimate act. It gives the stitcher a familiarity with the roughness of things. Real repair requires patience and a respect for entropy.

31 Rapacki, "Interview with Kader Attia."

32 Davis, "Soft Systems: Crafting an Architecture."

33 Basma Ghalayini, ed., *Palestine +100: Stories from a Century After the Nakba*, trans. Raph Cormack et al. (Manchester, UK: Comma Press, 2019).

34 Traditional tattoo revitalization movements are ongoing from the Arctic to the Pacific and across the American continents. These practices, until recently banned by settler authorities (church or governmental), are deeply embedded in the material and architectural practices that compose the inherited knowledge of sovereign Indigenous nations. Please note that, while support is welcome for free cultural expression through these markings and the residencies that are helping Indigenous artists share them, these techniques and patterns should not be appropriated. Tattooing often happens in ceremony and is tied to kinship relations that are specific to each nation and their homelands. For further reading, see Jana Angulalik, "Kakiniit: The Art of Inuit Tattooing," *Canadian Geographic*, July 26, 2021, https://canadiangeographic.ca/articles/kakiniit-the-art-of-inuit-tattooing/.

Conclusions

Full consensus—on history, on technology, on money—is not required to bring the future closer, but the thousands of tiny, productive steps between here and there will be more effectively taken by a crowd. The lone visionary-CEO-inventor hasn't got much to offer (and probably never did) because no single vision of what comes next is helpful for everyone. Let's instead look to the grandmas for advice. What would it feel like to move beyond an idea of nature that draws a single line from past to future, from primitive to civilized, trending slightly upwards or halting abruptly at Armageddon? A technocratic understanding of history posits that progress equals new technology equals better life, and, in many ways, this has played out—while sowing climatic and humanitarian crises.

Working with leftovers and stitching them back together resets the settler-colonial clock. It is a passionate admission of living inside ruins, and making use of what remains. Not a fresh start; a restart. Stitching, a repeatable practice without explicit beginning or predetermined end, counters linear time and hierarchical labor. This act makes clear that material, method, maker, and motivation fundamentally fit within the same thought. Stitching can help us think of design and people inseparably, a necessary step toward a building ethic that survives the next century. My grandmother grew up during the Great Depression and she saved everything: thread, rubber bands, scraps of paper. So did my mother, and so do I. These spare parts, collected in a junk drawer, become the needful medium to fix a problem, catch a thought, close a hole: all the mundane acts of a life lived resourcefully, carefully, on the edge of survival and the fulfillment of love. Stitching takes leftovers and makes them, if not new, then part of life again. It points to an ecological and social understanding that resists disposability; a sort of entwined material destiny between people and the stuff with which they surround themselves.

Felecia Davis, Didem Ekici, and Joar Nango on Stitching

What follows is a conversation with Felecia Davis, Didem Ekici, Joar Nanjo, and the *Material Acts* team. Stitching highlights practices that employ the act of the stitch as an architectural act that not only bridges materials, but also the way that we think about them and connect various systems of knowledge.

Each of your practices reinterprets and updates processes of textile production, opening pathways to new understandings of the craft, of surface, and of effect in architecture. The material act of "stitching" understands a stitch as a structural device that not only brings together materials, but also joins various systems of knowledge from different disciplines, geographies, and cultures.

Stitching is arguably the most manual, gestural, and directly human-oriented of the material acts examined in this project. It evokes an intimacy between the maker and the medium. What, for you, characterizes stitching as an act of making?

FD I'll jump in on this question. Working as an African American woman in architecture, I've spent a lot of time trying to understand how the culture from which my family comes from relates to what's going on in architecture. When I first started to learn architectural techniques, I was rebellious. After considering, for example, bell hooks's *Teaching to Transgress*, I calmed down as I recognized that my rebelling was coming from not seeing my own culture reflected and included in architecture. SOFTLAB is about connecting culturally with the things I grew up with and things that are a part of African American culture, and making space for these to be understood within architecture. You see acts of craft, of working with the body, throughout different art forms in African and African American culture.

To me, stitching is most prominently (metaphorically) related to the question—how do you stitch cultures? How do you bridge them together in a way that is hospitable, comfortable, and welcoming for a culture that hasn't necessarily been a part of the construction, the mother, or the foundation of architecture? This is the most important kind of stitching that I've been trying to do.

JN Talking and thinking around the metaphor and philosophical concept of stitching is rewarding and inspiring, but there's also something about the pure technology of stitching that I feel very drawn to and informed by. It's a very essential form of creation act; it's both so universal and so elementary. There's a deep humanity to stitching together. It is something that everyone does in one way or another, almost every day. For me, because I work with vernacular traditions, found and natural materials are very accessible, and I'm attracted to the technology of stitching as a very democratic type of methodology. Sewn Fish Stomach, 224

DE I think you both defined interesting and important characteristics related to stitching. As Joar said, at a basic level, it is universal—anyone can stitch. As an act of making, stitching involves an interplay between materials and human action at various levels, and it has been central in our conception of the idea of craft for centuries. Stitching, as a craft, is associated with knowledge, especially in more historical, cultural, and ethnographic traditions where it's a skill handed down through generations.

This leads to our next question, about the universality of stitching and transferability of it as a technology.

Felecia, in your work, we see a translation between cultures: between African American culture and the culture of the academic research lab. Joar, you conduct research in archives, often extremely colonial archives, to find traces of Indigenous methods that you make anew in the field. In other stitching practices, we observe similar forms of transfer, across geographies and between different actors. Within this web of extensive movement and circulation facilitated by stitching, what does it mean to innovate on existing vernacular cultures of making?

FD "Innovation" is partly what needs to be translated. Bringing together two spaces—culture and an academic research lab—requires a reframing of what we understand to be innovation, an understanding of different frames of knowledge, and the bringing of other frames of knowledge into what we classify as high research. Sometimes people can't see the problem, and half, if not more, of what we do as designers is frame a problem to try to allow for different ways of understanding.

Many of these cultural ways of knowing are not part of a lab environment and therefore are not seen as innovative. While working in Leah Buechley's High-Low Tech lab at MIT, it became clear to me that innovation is happening everywhere and to everybody. It's about perspective and the ability to imagine or dream a new place or world and having the faith to pursue that. One major aim of this lab was to view textile arts such as stitching, sewing, and embroidery-crafts often associated with women—as knowledge not just belonging in but also being integral to research in computer science. I think her technique was spot on, and others are doing similar work—for example, Robin Wall Kimmerer, in her book *Braiding Sweetgrass*. Innovation means other ways of knowing. It is the ability to see other things and make things appear differently.

DE I want to piggyback on what Felecia said. While I'm not a practicing architect and Felecia and Joar have more hands-on experience innovating existing textile arts and traditions of stitching, I want to note that throughout history, innovation has always been a part of what's been called traditional. When looking at the history of crafts, every generation reflects its own historical and social context, so it's never blind repetition. There is always innovation, which is important to stress because, generally, craft is often posed as something that is frozen, immobile, and unchanging—but it's always moving with the times.

JN I think innovation is something that can involve new, unexpected, and often unpredictable paths or solutions that can serve as a release from situations, conversations, or ways of thinking that are sometimes stuck in tradition.

When working in traditional craft, it is easy for people to become a little afraid of exploring or finding their own way, much like when following a recipe. Innovation, creation, and exploration loosen up this very static and often polarized thinking about tradition versus modernity. For example, in the "us versus them" way of thinking, innovation can create a third alternative—a new, constructive way of decomposing power structures that are embedded in historical or colonial systems.

When I say innovation, I'm also talking about art and strategies for confusion or playfulness. I often think about creativity as walking backward or insisting on doing something that isn't always necessary. While these types of activities can be nonsensical, they also offer new directions and release from very static power.

FD Continuing on this idea of playfulness—play is so important when working within tradition, particularly within craft, where the dominant method of learning is to closely copy and follow the person who is teaching you. Adding play to this system allows for something else to happen. Playfulness is super important to innovating because it takes you to a place that's potentially unfamiliar and gives you this other vantage point that allows you to see something new.

DE To add to the importance of playfulness, I think part of innovation relies on what is available to the maker at that point in time, whether that involves new materials or the socio-cultural moment that inspires the content of stitching. This obviously changes constantly, which drives innovation.

We want to turn to thinking about care practices and ethics of care. This is not a new conversation, and particularly when it comes to textiles, since textiles have traditionally been produced from animal matter, such as sheep's wool. Textiles have always been closely associated with the raising of livestock or tending to of flocks of animals and growing grounds.

Didem, could you offer a deeper historical context for questions of care when it comes to textile production? Joar and Felecia, can you expand on how you think about how to care, and the ethics of sourcing materials, perhaps in relation to how you carefully manage where materials come from?

DE Regarding the historical ethics of sourcing materials—my research focuses on the 19th century, a time when textile production and manufacturing experienced massive growth. This is a history that is obviously closely tied to colonial exploitation. Textile manufacturing initially exploded in Britain as cotton was sourced largely from its first colonies like India and then later in the USA, where cotton production was largely based on slave plantations and slave labor. So this question of ethics is not only about care of livestock, but also the forms of labor involved in textile production, which have historically been methods of mass-manufacturing developed during this colonial era. Systems that rely upon slave labor persist today in different forms, such as sweatshops in Southeast Asia and elsewhere, where workers are treated extremely poorly and paid very little to produce textiles directed to consumer markets in wealthier Western countries.

FD I think about this a lot while working with textiles. When you design something new, you're putting new things out into the world, and then what happens to that stuff? At SOFTLAB, the things we make are one-of-a-kind, but we're using industrial processes that are designed to mass produce. These processes could potentially end up in the sweatshops Didem mentioned or lead to more dumping in the Atacama desert. This has shifted our approach to making textiles. We're trying to use more biodegradable materials, but even producing biodegradable materials requires a lot of resources, such as water and care.

I'm at Penn State, which has a really strong agriculture department that houses a lot of sheep that get sheared every year. We've been thinking about what we can do with waste wool—how we can fully reuse and recycle it. I don't think anyone has found a solution yet to address every aspect of the cycle of sheep farming, from growing the wool on the sheep, to turning it into yarn and textiles, to ensuring that all of the textiles will be fully biodegradable. We've also been working with growing materials like mycelium, but the same issue exists there—once you have too much of something, no single thing can be the solution. These problems of labor economies, material surplus and waste, and how to care for the earth, need a patchwork quilt of differing solutions.

In our projects, we use hair Black human hair, to think about these issues through the lens of the afterlife of human hair waste. It serves as an intersection or nexus of topics such as African American presence and what Didem was discussing—the cotton industry's dependence on slave labor in this country in the 18th and 19th centuries. When looking at a material such as cotton, you can unfurl all of these various networks of relations, which reflects our approach in our lab. Knit Dreadlocks, 226

JN Your last comment is really interesting. It resonates with what I was thinking about earlier, how within any technology, there are different sorts of cultural value systems. I've been interested in the traditional ways of the nomadic reindeer herding culture from where I'm from, which has opened up a lot of interesting reflections for me

There is already much ethical consideration of reindeer herding and herding more generally, and how this practice connects to time, the land, and a certain way of being. The closeness to materials, harvesting practices, and weather, carries an ethical dimension to how people think about these material flows. This context is inspiring and a good model for sustainability and I find this to already exist in Indigenous reindeer herding culture.

While I don't herd reindeer myself, my family members do, and it's a culture that I was raised in and am very connected to. The protection of these cultural practices is important to me because, despite being threatened by industrialization, we continue to live on and remain connected to the land by these old systems and methods. The technology of these old ways and this culture of living and thinking in a closer, more humble way towards landscapes and material flows, has sustained us here for thousands of years, and this is an invaluable resource to learn from and shed light on. Like Felecia said, while our technology is a resource of knowledge, it might not offer a complete solution, so there is a need to work with patchworks of different technologies and ways of thinking.

FD The ethical question is a tough one because it depends on what frame you're in, and things are relative. I continue to find this problem really interesting as well as tricky, and it's one of the most important issues that we can engage in as designers.

JN Yes, and personally, being a part of a small group and feeling like I constantly have to fight to protect things that the rest of humanity has moved so far away from and lost in so many cultural practices—this overshadows other big questions on ethics.

FD You've all got my mind racing.

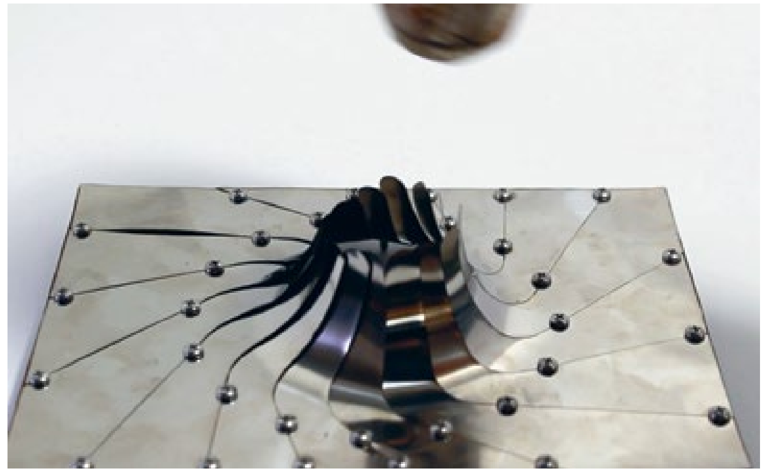
MATERIALS

Materials presented within these pages reflect research and experiments featured in *Material Acts: Experimentation in Architecture and Design*, an exhibition at Craft Contemporary in Los Angeles, CA, produced as part of 2024 Getty PST ART: Art & Science Collide. These materials intend to illustrate, give nuance to, and expand understandings of the acts of Animating, Disassembling, Feeding, Re-fusing, and Stitching. With attention to techniques of material change, these descriptions by the *Material Acts* curatorial team serve as a reference index for introductions, guides, and conversations collected in this volume.

Animating Materials

Responsive Bimetal

DOSU Studio Architecture

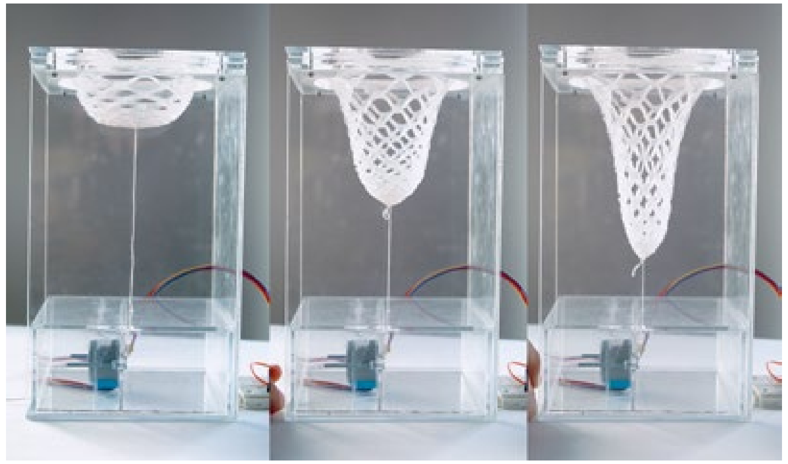


DOSU Studio Architecture, (top) *Oculus*, 2016, testing the curling properties of thermobimetal using a heat gun; (facing) *InVert*, 2020, mockups of window screens containing thermobimetal. Images courtesy of DOSU Studio Architecture. (Below) *Bloom*, 2011, installation view of an architectural application of thermobimetal. Image courtesy of DOSU Studio Architecture/ Materials & Applications.

Many buildings are embedded with means to respond to changes in their environment. These mechanical systems typically operate through electrical circuitry, sending inputs as signals to a central processing unit that in turn initiates a preprogrammed response, such as lowering a shading device or activating an electrical current. DOSU Studio Architecture's Doris Sung researches alternative models of responsiveness in building assemblies that do not require electrification or monitoring systems, relying instead on the innate behaviors of materials. Sung works with laminated sheets of different metal alloys, each with a distinct coefficient of expansion, to produce a laminated bimetal. As temperatures increase, one side of the lamination expands more than the other, causing the material to curl. In some of Sung's projects, these laminated pieces are hung from a supporting scaffold to create a screen that, during the warmest parts of the day, heats up and transforms to block solar heat gain.

Actuated Elastomers

Omar Khan



Omar Khan with the Situated Technologies Research Group, 2007. (Top) model demonstrating homeostatic principles of *Open Columns* and related projects; (below) elastomer arms, connector prototypes, and mold for component parts used in the assembly of *Open Columns*, designed to sense carbon dioxide in the air; (facing) *Open Columns* installation view. Images courtesy of Omar Khan.

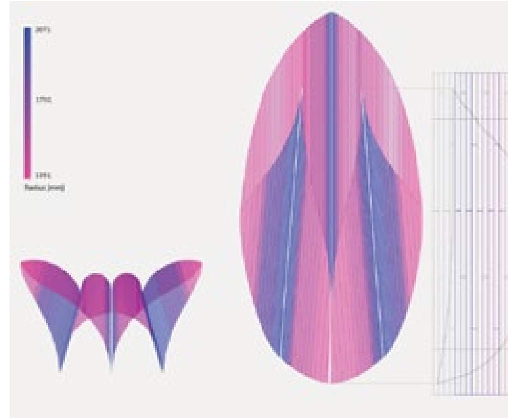
Omar Khan explores intelligence in materials through animated architectures. His research begins with homeostatic models, which are machines or devices designed or programmed to adapt and respond to their surrounding environment. Utilizing sensing equipment, mechanical assemblies, and urethane elastomers, *Open Columns* senses carbon dioxide in the air and uses this as a motivator for how it shapes itself. When it registers a certain level of carbon dioxide, the machine sends a signal to a series of actuators that raise or lower flexible conical columns. These columns, made from composite urethane elastomers, expand to fill a given space to disperse a crowd, thereby lowering carbon dioxide levels.

Additional acknowledgements: This research was led by Omar Khan (Situated Technologies Research Group) with James Brucz, Nick Bruscia,Gerardo Ciprian, Brian Clark, Dennis Cook, Joseph D'Angelo, Rafal Godlewski, Ashley Latona, Brian Podleski, Vail Rooney, and Mike Wysochanski.

Hygromorphic Wood

Dylan Wood

Institute for Computational Design and Construction, University of Stuttgart School of Architecture & Environment, University of Oregon



Dylan Wood with Institute for Computational Design and Construction, 2023, (top left) the moisture content of lumber boards is measured to determine a cutting strategy; (top right) *HygroShell*, diagram showing curvature of individual wood pieces; (facing) *HygroShell*, installation view. Images courtesy of ITECH/ICD/ITKE University of Stuttgart.

Like many structural systems, shell structures often require complex manufacturing, formwork, and intricate on-site logistics for assembly. Components must be machine-manufactured to a specific shape and then, once at the building site, lifted into place piece by piece, demanding immense energy expenditure and physical force. Dylan Wood lessens these demands by working with the inherent hygromorphic properties of wood to craft structural sheets that unfold into their intended curved geometry through air drying once on the construction site. Wood employs an algorithmic calculation of curvature potential to model each surface before construction, which predetermines the locations of interlocking connections, so structures may be assembled without formwork or external mechanical force and with minimal onsite work. This method has been used to produce lightweight, long-span roof structures.

Additional acknowledgements: The HygroShell was developed by the Institute for Computational Design and Construction is led by Dylan Wood, Laura Kiesewetter, and Achim Menges. HygroShell was developed with ITKE (Axel Körner, Kenryo Takahashi, Jan Knippers) with development and fabrication support from Andre Aymonod, Wai Man Chau, Min Deng, Fabian Eidner, Maxime Fouillat, Hussamaldeen Gomaa, Yara Karazi, Arindam Katoch, Oliver Moldow, Ioannis Moutevelis, Xi Peng, Yuxin Qiu, Alexander Reiner, Sarvenaz Sardari, Edgar Schefer, Selin Sevim, Ali Shokri, Sai Praneeth Singu, Xin Sun, Ivana Trifunovic, Alina Turean, Aaron Wagner, Chia-Yen Wu, Weiqi Xie, Shuangying Xu, Esra Yaman, and Pengfei Zhang and additional support from Katja Rinderspacher, Simon Bechert, Michael Schneider, Michael Preis`ack, Sven Hänzka, Sergej Klassen, Hendrik Köhler, Dennis Bartl, Sebastian Esser, Gregor Neubauer, Gabriel Kerekes and the Institute for Engineering Geodesy (IIGS).

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Lumber
After Architecture

198 Delaminated Lumber
HANNAH

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196 Jammed Gravel
Gramazio Kohler Research

200 Biogel Sheets
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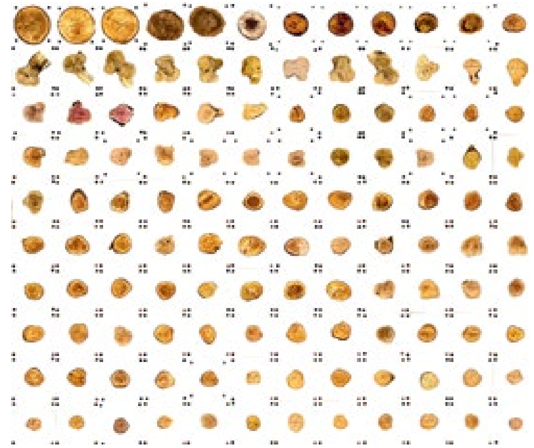
Non-dimensional Lumber

After Architecture



After Architecture, *Tangential Timber*, 2021–22, (top right) image of timber cookies arranged into a matrix by size; (top left) installation view of timber cookies assembled into an architectural vault; (below and facing) detail views of computationally cut "cookies." Images courtesy of After Architecture.

In North America, wood is most often utilized in building applications as dimensioned lumber, made from harvested timber hewn and milled into standard-size units. This industrialized process links the value of wood to its ability to be standardized. Converting timber into lumber can be a wasteful process, as irregularly shaped or infested timber is shredded for chips or pulp or discarded outright. After Architecture's project *Tangential Timber* enacts an alternative workflow that takes advantage of the capacities of non-dimensional lumber. The process begins by collecting irregular waste wood and cutting it into disc-like cross sections called "cookies." These cookies are digitized as images and then fed into a parametric script that aggregates and interlocks the digital cookies into three-dimensional forms, such as vaults. Because they are joined without binders, the cookies can be disassembled while retaining their structural capacity.

Additional acknowledgments: This research is led by Katie Macdonald and Kyle Schumann with Abby Hassell, Sonja Bergquist, Sophie Depret-Guillaume, Cecily Farrell, Alex Hall, Caleb Hassell, Abbey Partika, Russell Petro, Emily Ploppert, Dillon Mcdowell, Jonathan Spears, Jolie Talha, and Annabelle Woodcock.

Jammed Gravel

Gramazio Kohler Research

Gramazio Kohler Research and Self-Assembly Lab, *Rock Print*, 2015, (top) the installation is disassembled by the recoiling of string; (below) detail view of *Rock Print* installation, built from low-grade granular material and constructed by robotic machines. Images courtesy of Gramazio Kohler Research/Chicago Architecture Biennale. (Facing) *Rock Print Pavilion*, 2015. Image courtesy of Gramazio Kohler Research.

Aggregate materials rely on a binding agent to become structurally efficient. In the case of concrete, cement triggers an irreversible chemical transformation when combined with water and carbon dioxide, setting, hardening, and adhering to aggregates like sand and gravel. Gramazio Kohler Research explores a different, reversible method for holding aggregate together. In the projects *Rock Print* and *Rock Print Pavilion*, a robotic arm unspools twine between layers of loose gravel. As the layers vertically accumulate, the coils of twine provide enough additional friction for the aggregate to hold together under its own weight. This technique, called jamming, temporarily fixes the otherwise fluid material into an array of irregular, yet structurally sound forms. Unlike typical binders, the twine's hold on the aggregate is reversible; the twine can be re-coiled, causing the aggregate to collapse back into a loose pile and return to a fluid state — unchanged from its original material composition.

Additional acknowledgements:
This project is by Gramazio Kohler Research with Petrus Aejmelaeus-Lindström (project lead), Gergana Rusenova (project lead), Hannes Mayer (Senior Researcher-in-Charge), Dr. Ammar Mirjan, Esther Lombardini, Jesús Medina Ibáñez, Selen Ercan, Sandro Meier, Michael Lyrenmann und Philippe Fleischmann.

Delaminated Lumber

HANNAH

HANNAH, *Unlog*, 2021, (top) a robotic arm with a custom bandsaw end effector slices infested tree logs into units that stretch open like accordions; (bottom right) detail view of *Unlog*; (bottom left) installation view of *Unlog* in its stretched-open state. Images courtesy of HANNAH.

In traditional lumber production, individual dimensioned units (such as 2x4s) are extracted from harvested logs, leaving behind substantial wood scraps. HANNAH has employed kerfing techniques, which apply a series of equally spaced, offset cuts to utilize entire logs. In their project *Unlog*, a robotic mill cuts a log lengthwise in an alternating pattern, allowing the log to unravel like an accordion. The cut paths can be adjusted to follow the natural curvature of a log, making the technique applicable to a wider array of inventory. The logs are cut off site, transported in their collapsed, original form, and then stretched on-site into A-frame structures. This process can also occur in the other direction — the logs can be refolded into their compact form and transported to other sites.

Additional acknowledgments:
HANNAH is led by Leslie Lok & Sasa Zivkovic (principals and lead designers) with Lawson Spencer (team leader) and Collette Block, Sahil Adnan, Yehong Mi, Shenkung Yang, and Andreya Zvonar.

Biogel Sheets

Sutherlin Santo

Sutherlin Santo, *Biocraft*, 2020, (top) a table showing sheets of varying rigidity; (below) plant-based biomaterial samples made from 3D-printed biopolymer gels; (facing) plant-based biogel is extruded through a 3D printer to form multi-layered sheets. Images courtesy of Sutherlin Santo.

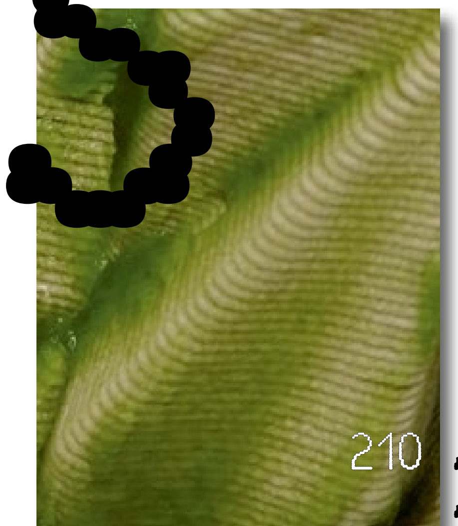
From metals to concrete, most building materials are inorganic and break down over time only through mechanical or chemical weakening of their structure. Sutherlin Santo uses plant-based matter to create biodegradable "biogel" that can take on a range of mechanical and visual properties. In their experiments, the biopolymer gel is fed into a paste extruder on a robotic arm and printed through predetermined toolpaths into multi-layered sheets with variable rigidity and opacity. Sutherlin Santo uses this process to produce elements from different biogel mixes across various scales, from tile-sized samples to a stool to wall-cladding system. One biogel in particular absorbs and sequesters carbon from its surrounding environment, acting as an organic air filter. Once this gel is saturated with toxins, decomposition is induced through biodegradation, a process which harnesses the digestion of microorganisms to break down the material structure of the biogel.

204 Mycelium Columns
Yogiaman Tracy Design

206 Bacterial Cellulose Sheets
Maru Garcia

Feeding Materials

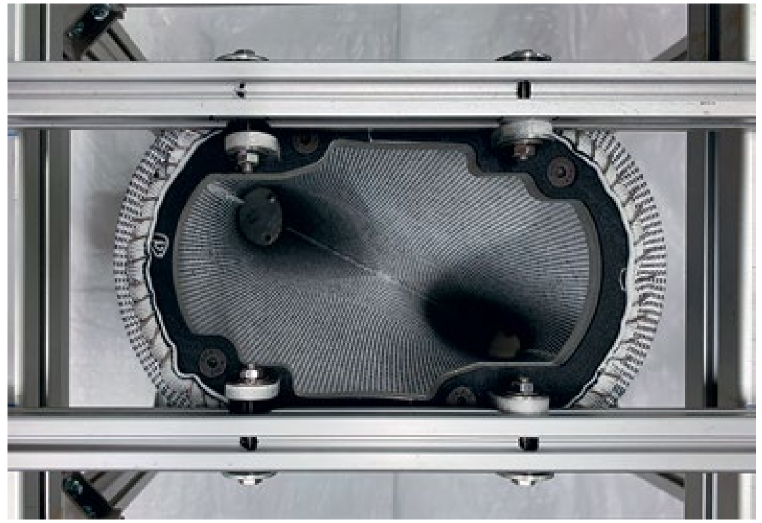
208 Biocalcified Paper Foam
Soft Matters



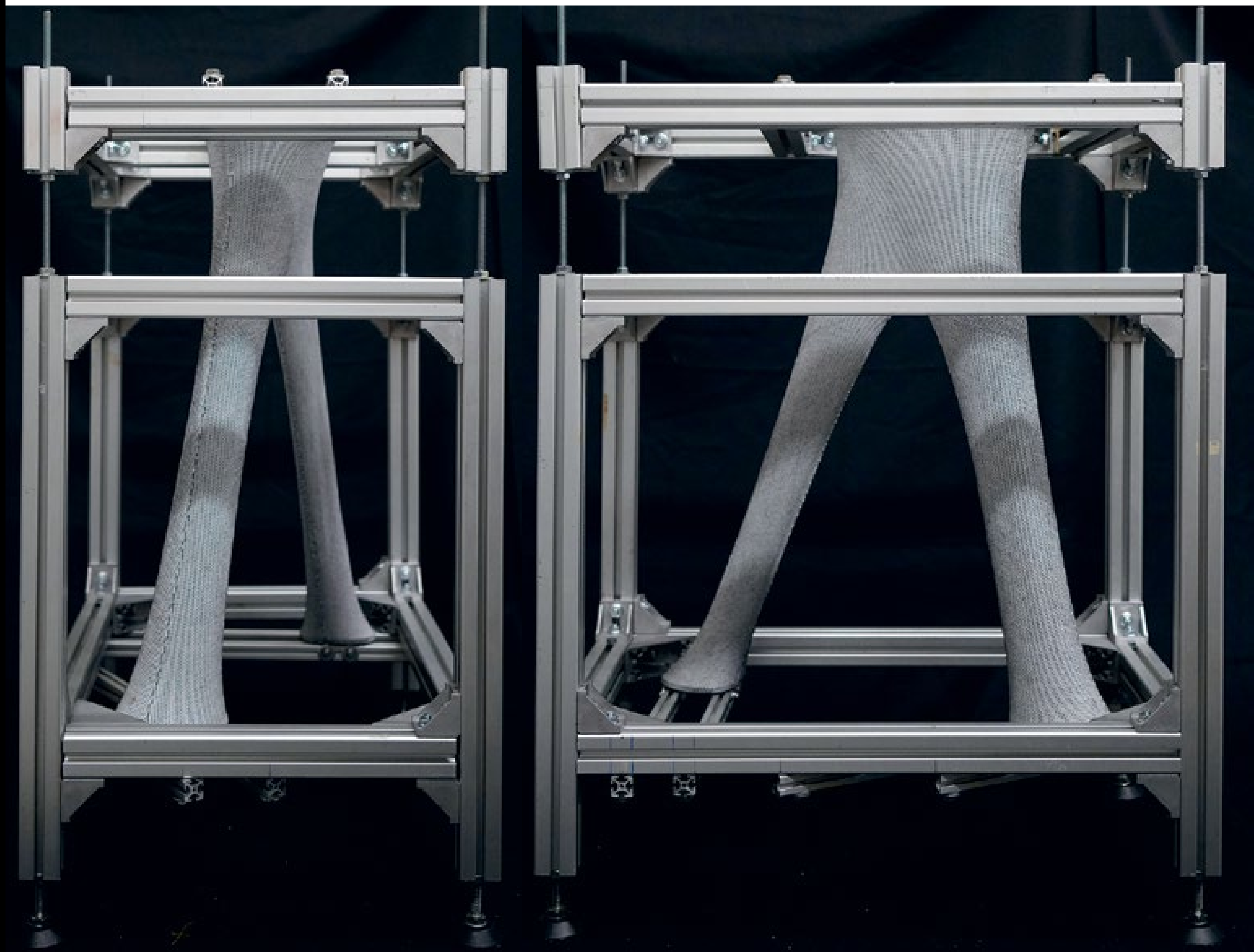
210 Algae-laden Hydrogels
Assia Crawford

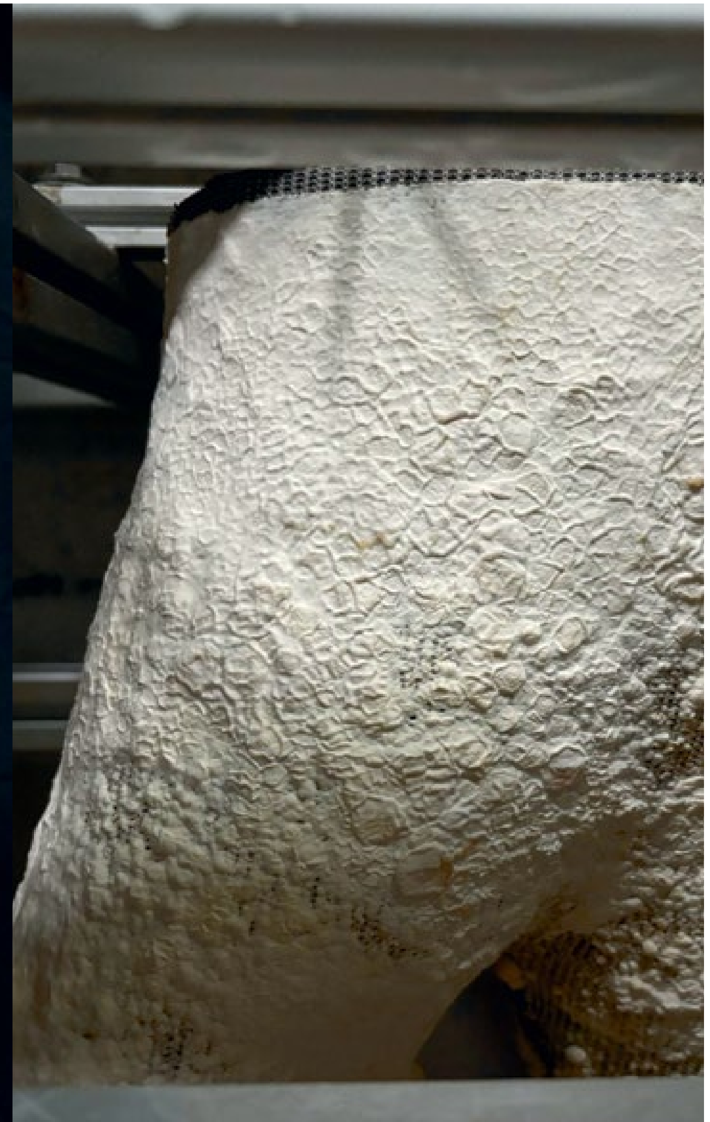
Mycelium Columns

Yogiaman Tracy Design



Yogiaman Tracy Design, *Growing Scaffold*, 2020, (top) top view of knitted mold and aluminum support jig for mycelium column; (below) detail view of mycelium growth over knitted mold; (facing) side view of knitted mold and aluminum support for mycelium column. Images courtesy of Yogiaman Tracy Design.





Many building techniques employ temporary scaffolds to support primary materials while they cure and gain structural integrity. In common practices, these scaffolds are removed and then discarded. *Growing Scaffold* utilizes 3D CNC-knitted textiles as a formwork that remains, instead, as a substrate that hybridizes with a mycelium application into a textile-mycelium column. This method allows for the production of non-linear, freeform geometries that, once filled with compacted wood waste, provide both food and formal constraints to the resulting structural component. Organic cotton yarn within the formwork guides the growth of mycelium root-like filament network (hyphae) through the knitted formwork, which is ultimately subsumed by the living material. As living matter, the mycelium requires careful cultivation and the monitoring of temperature, humidity, and light conditions. Yogiaman partners with Mycotech, a biotechnology company, to sustain the textile mycelium composite as material stock.

Additional acknowledgements: This research is led by Christine Yogiaman and Kenneth Tracy, with Christyasto Priyonggo Pambudi, Chia Pei Zhi, Quek Yu Han, with support from IDC, Singapore University of Technology and Design, DManD, Singapore University of Technology and Design, and Mycotech Lab.

Bacterial Cellulose Sheets

Maru Garcia

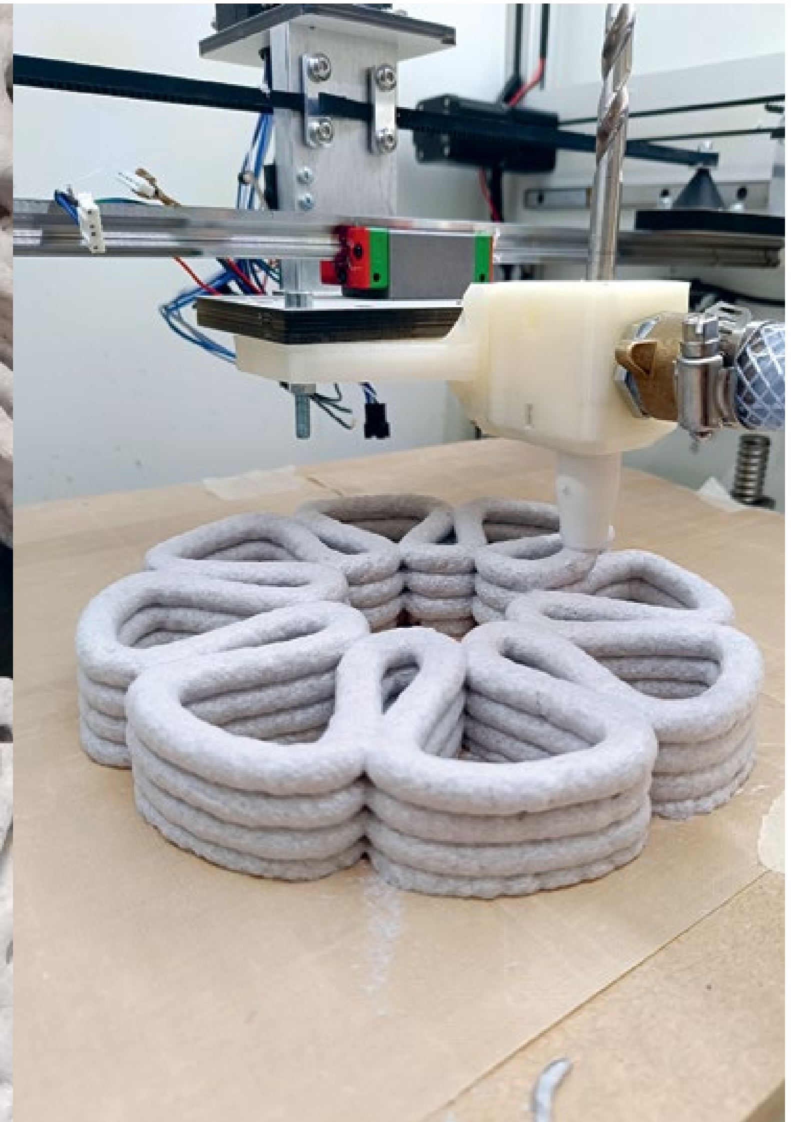
Maru Garcia, *Shelter*, 2021, (top) process documentation of artist working with SCOBY (symbiotic culture of bacteria and yeast); (below) durable cellulose skin grown from SCOBY; (facing) cellulose skin grown from SCOBY hangs to dry. Images courtesy of Maru Garcia. Photographs by Jack Bool.

Artist and chemist Maru Garcia works with living matter. Working between various vessels—a kitchen sink, a bathroom tub, custom fabricated pools—Garcia tends to live symbiotic cultures of bacteria and yeast (SCOBY), harvesting films of cellulose to produce disposable architectural skins. Her research combines artistic and scientific modes of production, integrating laboratory and fieldwork practices with her background in plant chemistry and the pharmaceutical industry. Her work often transforms gallery and museum spaces into laboratory settings, where weekly acts of feeding, growing, and monitoring of the SCOBY composition take place. In the gallery, these symbiotic cultures of bacteria and yeast produce bacterial cellulose sheets, which are then harvested to create a lightweight membrane.

Biocalcified Paper Foam

Soft Matters

Soft Matters, *All flowers are of paper*, 2022–2024, (top) foam test sample before (left) and after (right) calcification; (below) 3D printer extrudes paper waste pulp into folded pattern; (facing) detail view of 3D-printed paper waste pulp. Images courtesy of Soft Matters.



In their research, Soft Matters (led by Aurélie Mosse) induces chemical reactions with living matter, primarily bacteria, resulting in both their death and a structural byproduct. In *ImpressioVivo*, paper waste is ground into powder and mixed with a resin-based foaming agent, starch glue, and water, to form a foam. This foam mixture is then 3D-printed and, once dry, submerged in a solution of *Sporosarcina pasteurii*, allowing the bacteria to be fully absorbed by the foam. In the final step, the print gains rigidity as it is soaked in a calcifying solution, causing the bacteria to form the carbonate mineral calcite, entombing it and ultimately leading to apoptosis — the death of cells. This workflow depends on the biochemical reactions of an animate input, the bacterial colony, and culminates in deactivating the bacteria to achieve the material's use state. The labor of sustaining this live stock—maintaining proper conditions and feeding schedules—ultimately ends in a designed death.

Additional acknowledgments: The *ImpressioVivo* team involved in these experiments is made up of Aurélie Mosse, Daniel Suarez Zamora, Quentin Poudoulec, and Tom Samson.

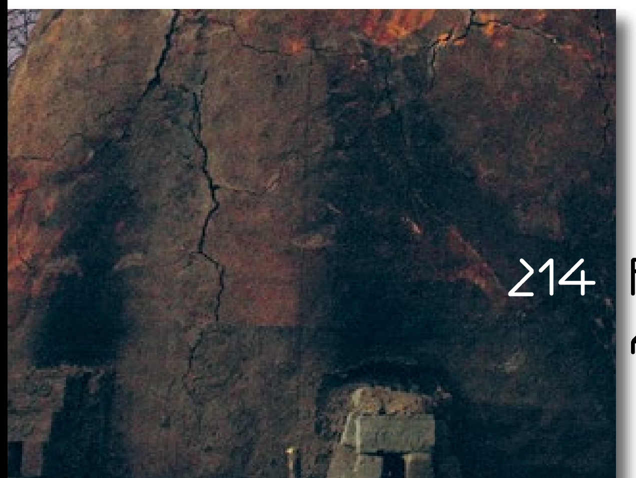
Algae-laden Hydrogels

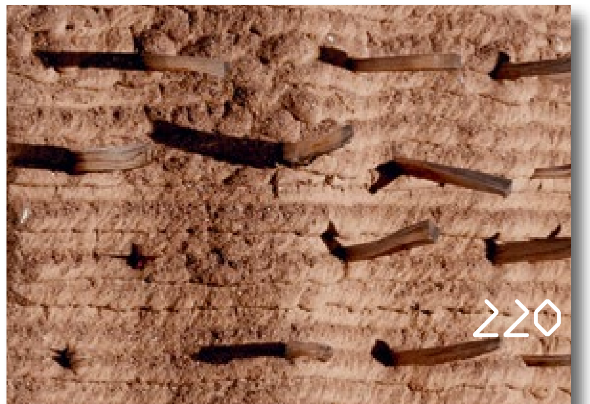
Assia Crawford

Assia Crawford, *Algae-laden Hydrogels*, 2020, (top) algae culture system; (below) dish showing growth progress of different algae samples; (facing) 3D-printed clay vessels with algae growth. Images courtesy of Assia Crawford.

Assia Crawford embeds clay and ceramics with living matter, or metabolically active microalgae (*Chlorella vulgaris*). Working in a carefully maintained algae control room, Crawford and her team propagate various strains and monitor their growth in clay substrates of different makeups. The grown algae strains are centrifuged into a dense slurry, which is mixed with a gelling agent to produce a hydrogel. This gel is then painted onto 3D-printed clay vessels filled with nutrient-enriched water. To cultivate the algae, Crawford and her team spray the vessels with deionized water once a day and place them under growth lights overnight. The resulting building blocks can be interlocked to form partitions, integrating metabolic processes—namely photosynthesis—into otherwise abiotic assemblies.

Re-fusing Materials

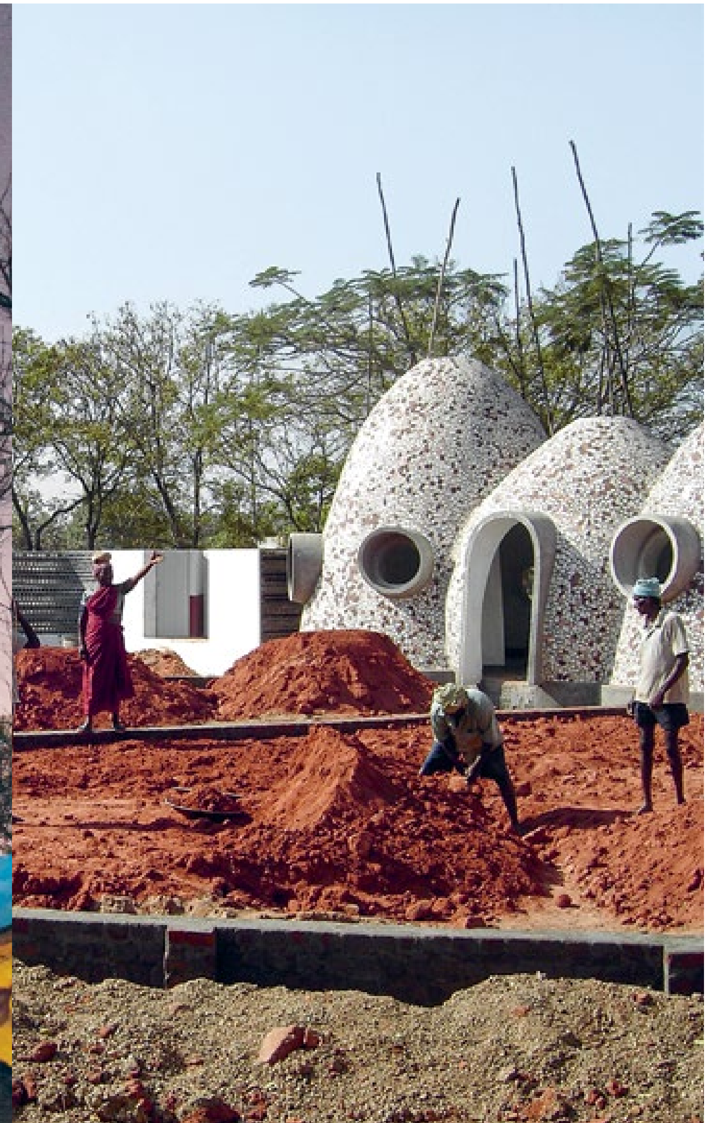




Fired-on-site Masonry

Anupama Kundoo

Anupama Kundoo Architects, *Volontariat Homes for Homeless Children*, 2008–2010. (Top) bricks are placed inside a domed structure which also operates as the kiln; (below) construction view of houses, photograph by Sonja Winkler; (facing) the mud house is fired in situ to complete its construction, photograph by Javier Callejas. Images courtesy of Anupama Kundoo.

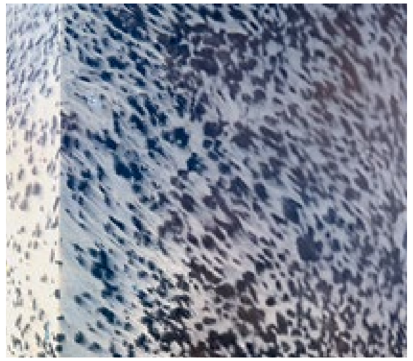


Masonry materials like brick are typically fired at a production facility before being transported to a construction site. In the firing process, about 40 percent of the heat generated is absorbed by the kiln itself. In her practice, Anupama Kundoo works to recuperate some of this energy loss, by building structures out of unfired mud and baking them in situ to complete their construction. The *Volontariat Homes* project is a series of domed houses built in Pondicherry, India, using mud bricks and mud mortar. Additional bricks and other mud products, such as tiles and kitchenware, were placed in the house interiors. The houses and their contents were then fired into conventional brick and ceramics, gaining material strength and durability through the process. The project expenses are mostly directed to manual labor, rather than purchased materials, thus directing funding towards local economies rather than globalized material supply chains.

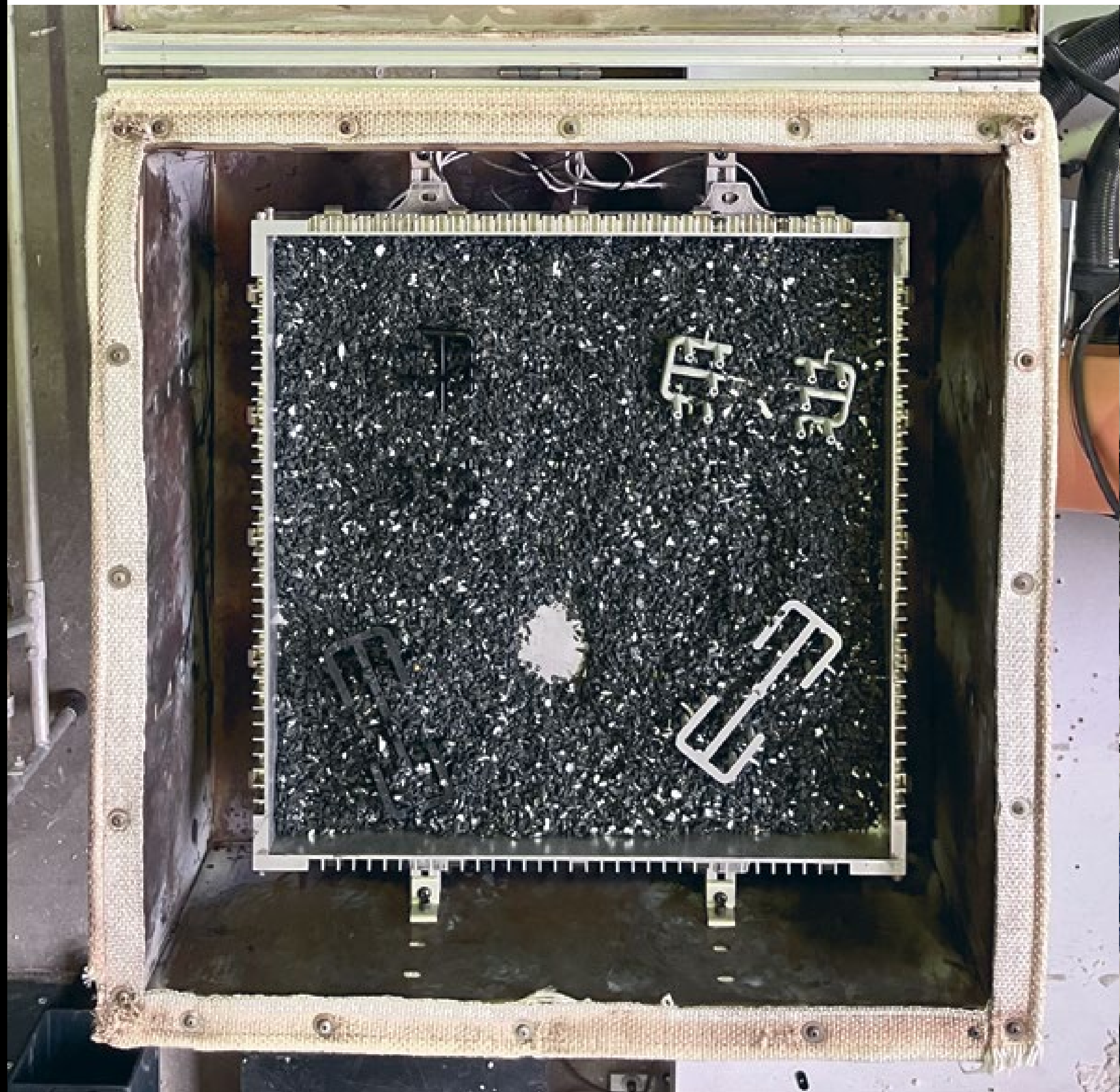
Waste Plastic Cladding

Post Rock





Post Rock, *After Auto*, 2024, (top) early prototypes of refused waste plastic; (below) detail view of automotive waste plastic stock; (facing) a mold is filled with waste plastic for slip-casting. Images courtesy of Post Rock.

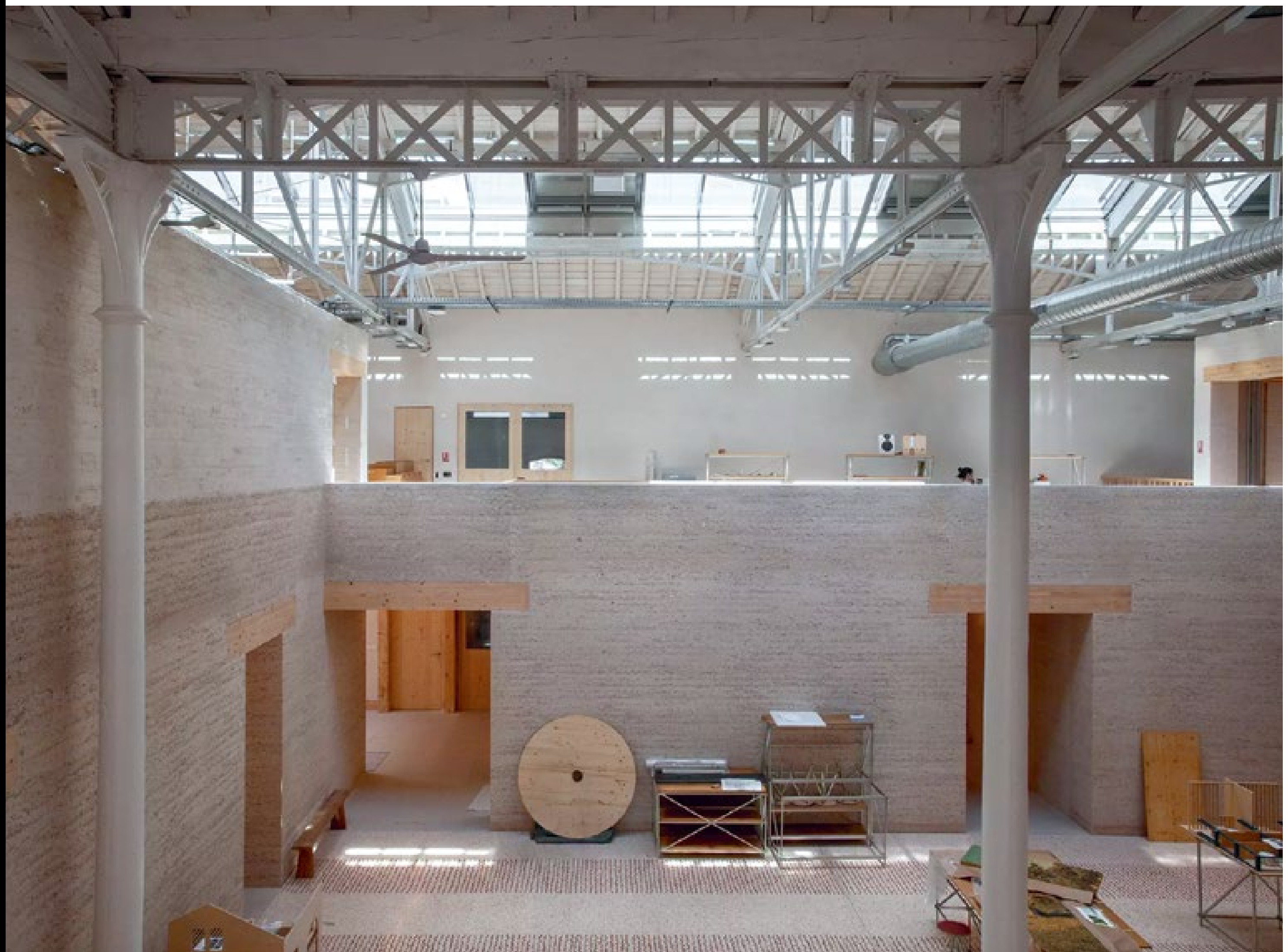



Post Rock's work is informed by the discovery of plastiglomerate, a new type of rock composite that has entered our planet's sedimentary record. Made up of plastics, sedimentary grain, and other debris, plastiglomerates challenge the traditional dyad of "natural" and "unnatural" materials by incorporating both. Attempting to simulate these geological processes, Post Rock fuses plastic waste diverted from auto-manufacturing in the Detroit-region into building components. The collected plastic waste is processed in two ways: on-site, where it is stacked and thermocast, and in the lab, where it is placed in a rotating thermoforming mold that gives it shape. In some cases, the outcomes of this workflow retain traces of the particular batch of waste plastic, leading to variability in color and texture in the finished product. Noting the regional specificity of waste streams, Post Rock speculates that the specificities of different waste plastics' "geographies" could inform or lead to differing composite materials being casted into architectural components.

Additional acknowledgments:
Post Rock is led by Meredith Miller, Thom Moran, and Chris Humphrey.

Bioregional Building Products

Assemble, Atelier LUMA, and BC architects & studies & materials



Atelier LUMA with Assemble and BC architects, *Lot 8*, 2019–2023, (top left) documentation of material testing, in which only materials classified as waste products, by-products, or under-valued materials were used; (top right) acoustic composite panels made for *Lot 8* from the marrow of sunflower stems, colored with mineral pigments. Photographs by Adrian Deweerdt. (Facing) Inauguration of *Lot 8*. Photograph by Joseph Halligan. Images courtesy of Atelier LUMA.

Industrial building products are often sourced from major manufacturing regions, with their long-distance transportation to construction sites accounting for a substantial share of their embodied carbon. Moreover, differences in the material composition of these products are most often the result of industry standards and regulatory regimes, rather than the outcome of regional variations in stock, such as local tree species and geological substrate. For the *Lot 8* project at Le Magasin Électrique, Atelier LUMA with Assemble and BC architects sought to initiate a more sustainable different relationship between the process of building and the project locality's material economies. Rather than relying on transcontinental supply chains, they sourced and processed nearly all of the materials for the project within 70km of the site. The only raw materials that were used at Le Magasin Électrique were classed as waste products, byproducts or under-valued materials. During the building process, demolished materials were, where possible, fed back into new construction. Terracotta tiles that fell off an extant roof were crushed, mixed with lime stripped from the building's original walls, and used to patch existing damage. Rice straw and sunflower stems harvested from the area were bundled and embedded within wall assemblies as thermal and acoustic insulation. In this way, construction became a means of testing and refining local recipes, rather than implementing a set of standardized finishes predetermined by a specification document.

Additional acknowledgements: Design Team: Atelier LUMA, Assemble, BC architects & studies & materials, Oda - Ostrowski Demuyter Architectes, Myamo, Betrec Ingenierie, Chris Posma Synefs Consult, Bas Bvba, Socotec, Bdm, Domene Scop, A-Tech Midi, Cabinet Lm Conseils, Lean Prévention, Terao, Association Apte - Sebastian Dutherage, Carsat, Adret, Estenea. Material Development: Atelier LUMA, BC materials, Lukas Wegwerth, Établissemen, Brissaud, Association Le Village, Actus Et Regard, Plâtre Vieujot, A-Tech Midi, CSTB, CTTM, Ets Carré, Critt Bois. Rachid Boukenhaf, AATB, Nebraska. Site Constractors, Tanzi, Guintoli Nge, Atelier Kara, Scop La Pierre Au Carré, Brique, Technic Concept, Rachid Mizrahi, Novacier, Menuiserie Corrèze, Ckat Aménagement, CVI, CLP, Calvo, Snef, Sarl Fernandez & Fils, Het Leemniscaat, Briseno, Tonello, Citynox, Apte, Association Le Village, Nebraska, Solid Travaux, Actisol

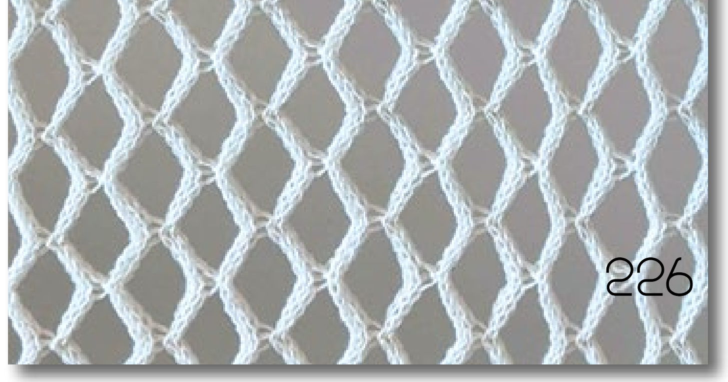
Printed Adobe

Rael San Fratello

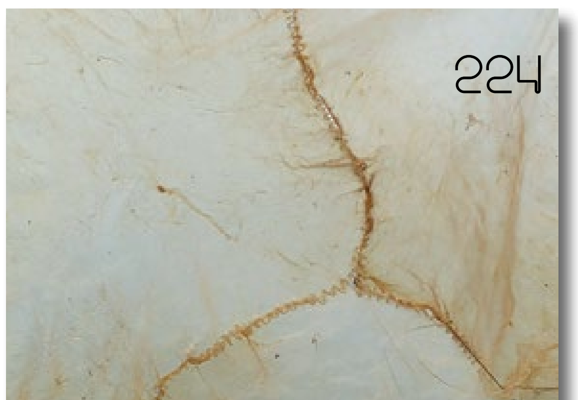
Rael San Fratello, *Hearth*, 2019. (Top) construction documentation showing a portable SCARA robot designed for in situ 3D printing adobe. Image courtesy of Rael San Fratello. (Below and facing) 3D-printed adobe prototypes and fragments incorporating earthen material from Rael's ancestral land. Photographs by Tag Christof.

Adobe is an earthen construction technique that has been used for centuries by Indigenous societies in regions worldwide. In the American Southwest, adobe construction is traditionally performed by hand, setting adobe blocks with adobe mortar. In site-specific projects in Colorado and New Mexico, Rael San Fratello has developed a mechanized workflow deploying the clay-rich soil of the land as input for large-format 3D printing of adobe structures. The outcomes of this process gain structural capacity not through the aggregation of discrete units like in traditional adobe block construction, but rather through the continuous folding of the extruded adobe onto itself in a self-structuring and gestural pattern. The printing apparatus is installed on a large truck bed, and is mobile enough to be transported onto a site, where local soils can be harvested and fed into the printing pump.

Stitching Materials



226 Knit Dreadlocks
SOFTLAB



224 Sewn Fish Stomach
Joar Nango

228 Fiber-rich Earthen Textile
Natural Materials Lab

Sewn Fish Stomach

Joar Nango

Joar Nango, 2019. (below right) washed halibut stomachs lying in a tub; (top right) flayed halibut stomach stretched over frame to dry; (below left) screen made from dried halibut stomach stitched together using reindeer sinew. Images courtesy of Joar Nango.

Skievvar recovers and adapts an Indigenous practice of the oceangoing Sámi people from the region encompassing northern parts of Norway, Sweden, and Finland. The technique was first encountered by Joar Nango in the archives of Norwegian scholar Just Knud Qvigstad in the form of a text without illustrations, necessitating a translation into a physical process that required iterative experimentation. Informed by Indigenous handicraft (*duodji*), Nango and frequent collaborator Sara Inga Utsi Bongo prepare everyday items and screens utilizing halibut stomach lining and reindeer sinew sourced from the region. Called *skievvarcoalli*, these screens are made by drying, oiling, and stretching harvested halibut stomach across wooden frames, and are typically used to cover windows and apertures in outhouses and other simple buildings.

Knit Dreadlocks

SOFTLAB

SOFTLAB, *Dreadlock Series*, (top) SOFTLAB investigates how Black hair technique of dreadlocking can be incorporated into architectural weaving; (below) knit flat panel with wool I-cords, 2022; (facing) model knit with a flatbed knitting machine, sewn into a tube, and stretched into place, 2022. Images courtesy of Felecia Davis/SOFTLAB.

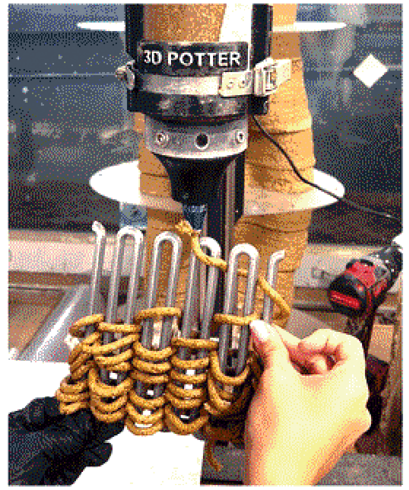
Hair is a ubiquitous, naturally occurring material, associated with numerous techniques of structuring, shaping, and styling. Felecia Davis of SOFTLAB specifically adapts locking and dreadlocking, techniques belonging to a tradition of Black cultural practices, to a scale beyond the individual body. These techniques involve twisting and felting hair until it forms a thickened mass, or loc. If a braid of hair starts the loc, this process can be translated into a rule-based grammar, allowing it to be written as computerized code. In the project *Dreadlock Series*, Davis works with textile artist Ian Danner and designer Hiranshi Patel to develop a series of knitted fabrics. As the fibers are felted, the cords gain durability and structural potential.

Additional acknowledgements: The core *Dreadlock Series* project team includes Felecia Davis, Ian Danner, Aysan Jafarzadeh, and Hiranshi Patel.

Fiber-rich Earthen Textile

Natural Materials Lab

PLAIN WEAVE



TWILL WEAVE

Natural Materials Lab, *Digitally-Woven Lattice Structures*, 2024, (top) material samples of digital weaving techniques with earth-fiber composites to create structural lattice structures; (below) prototypes and material samples stored in the laboratory; (facing) prototype for stackable "brick" of woven earthen fibers. Images courtesy of Natural Materials Lab/Lola Ben-Alon.

Most textiles, in both wearable and architectural applications, now contain synthetic fiber reinforcement. These fibers are often petroleum-based, resulting in a substantially higher carbon footprint compared to organic or biotic fibers. Natural Materials Lab, led by Assistant Professor Lola Ben-Alon, explores mixtures of geo-materials with plant fibers to create feedstock for 3D-printed structures that may achieve similar strength to synthetic lattice structures. The introduction of vegetative fibers and other biopolymers, including agro-waste products, into clay-rich soils can improve ductility and thermal resistivity of the fabricated building assemblies, ranging from mass-insulation walls to paper-thin partitions.

Additional acknowledgements: This project at the Natural Materials Lab is led by Lola-Ben Alon, with contributions from lab student assistant Valery Kate Perez.

Biographies

Adobeisnotsoftware

Adobeisnotsoftware is the earthen education and advocacy arm of Loescher Meachem Architects, a California-based architecture firm, founded by Ben Loescher, that specializes in adaptive reuse, high-performance workplaces, technical environments, and new capacities of adobe construction. Through public talks and workshops, the group disseminates know-ledge of building with and caring for adobe structures.

After Architecture

After Architecture is an architecture studio based in Charlottesville, Virginia, led by Katie MacDonald and Kyle Schumann. From building-scale construction to joint details, the studio uses computational tools to find new applications for industrial waste output and non-industrial materials, such as non-linear wood and invasive species of bamboo. In doing so, After Architecture develops altered building methods that respond to, and ease, the construction industry's dependence on rationalized and extractive manufacturing processes.

Amy Zhang

Amy Zhang, Assistant Professor at New York University, is an anthropologist and political ecologist whose research investigates the interaction of urban and environmental systems. Her first book *Circular Ecologies: Environmentalism and Waste Politics in Urban China* (Stanford University Press, 2024) is a study of the implementation of technologies and infrastructures to modernize a megacity's waste management system and the grassroots ecological politics that emerged in response.

Anupama Kundoo

Anupama Kundoo is an architect and the director of Anupama Kundoo Architects, based in Berlin, Germany, and in Pune and Pondicherry, India. Whether designing housing or testing clay firing techniques, the practice's work approaches the con-struction process as a means of cultivating and disseminating non-industrial material knowledge.

Assemble

Founded in 2010, Assemble is a multi-disciplinary collective working across architecture, design, and art with a demo-cratic and co-operative working method that enables built, social, and research-based work at a variety of scales.

Assia Crawford

Situated in wet rooms of a laboratory facility at the University of Colorado, Assia Crawford's research challenges the inanimate status of architectural materials by embedding living matter into familiar craft substrates, such as clay. By activating otherwise abiotic structures, the designer and her lab team speculate on modes of performance, such as carbon sequest-ration by algae-laden hydrogels.

Atelier LUMA

Atelier LUMA, the research design lab of LUMA Arles, explores the design possibilities of non-extractivist and undervalued local materials like industrial byproducts and waste, as well as lesser-considered plant material such as algae and invasive species. Their bioregional research has produced outputs ranging from bioplastic tiles dyed with algae, to walls and panels made of salt, waste soil, and plant fibers. LUMA platforms collabor-ation, both on a regional scale with actors including local farmers and builders, and on an international scale with other research institutions and partners such as Assemble and BC architects.

BC architects

BC architects & studies & materials is a Brussels-based workers' cooperative founded by Ken De Cooman, Nicolas Coeckelberghs, Laurens Bekemans, and Wes Degreef. Rather than relying on transcontinental supply chains and universally standardized building systems, BC architects advances bioregional modes of construction that draw on local material sources and cultures of building knowledge.

Caroline A. Jones

Caroline A. Jones is an art historian who studies modern and contemporary art, focusing on its technological modes of production, distribution, and reception,

and on its interface with science. Her recent research, gathered around the exhibition *Symbionts* and the publication of the same name, examines the ecological and kin relations of symbiosis and commensalism surfaced by contemporary "bio-art" practices, which critique Western philosophies of individualism and autonomy.

Charlotte Malterre-Barthes

Charlotte Malterre-Barthes is an architect, urban designer, and Assistant Professor of Architectural and Urban Design at the Swiss Federal Institute of Technology Lausanne, where she leads the research laboratory RIOT. Her research examines the political economy of space production and urgent issues in contemporary urbanization, material extraction, and climate. While a professor at Harvard Graduate School of Design, she launched the "Global Moratorium on New Construction" initiative that interrogates current protocols of development.

Didem Ekici

Didem Ekici, Associate Professor at the University of Illinois Urbana-Champaign, is an architectural historian. Her research interests revolve around the mechanisms, both technical and cultural, through which the built environment has modulated notions of health and gender. In her books *Textile in Architecture: From the Middle Ages to Modernism* and *Body, Cloth, and Clothing in Architecture from the Age of Mass Manufacture to the First World War*, she examines these histories through the shifting status of textile.

DOSU Studio Architecture

Directed by Doris Sung, DOSU Studio Architecture develops material systems that respond to changes in their environment without the use of electrification or monitoring. The studio explores models of responsiveness that harness innate material properties, such as differences in the contraction rates of metals, to initiate changes in form and performance.

Dylan Wood

Dylan Wood is an Assistant Professor of Architecture at the University of Oregon whose work takes shape at the intersection of material-responsive computational design and advanced manufacturing. Through research that unfolds across architectural practice, academic fabrication spaces, and commercial enterprises, Wood engages methods that explore how computational design enables simple, material-effective construction as well as novel geometries and functionality.

Elsa MH Mäki

Elsa MH Mäki is an architectural designer, professor, and writer who comes from the Anishinaabek family in Minneapolis. Her work focuses on borders, living environments, and Indigenous futures, and takes form as sculpture, cartography, immersive theater, and design. She has drawings in the #StandingRockSyllabus and the book *Empire's Tracks: Indigenous Peoples, Racial Aliens, and the Transcontinental Railroad* by Manu Karuka (University of California Press, 2019).

Gramazio Kohler Research

Situated within the research facilities of ETH, Gramazio Kohler Research experiments with additive robotic fabrication to make non-standardized architectural components. In their work with robotic tools, the team, headed by Fabio Gramazio and Matthias Kohler, scripts code to guide the aggregation of fluid matter, such as low resolution gravel and mud, into carefully calibrated and structurally active formations.

HANNAH

Directed by Leslie Lok and Sasa Zivkovic, HANNAH is an architectural office based in Ithaca, New York. The practice retools digital manufacturing techniques to exploit the specific capacities of building materials, such as the pliability of wood when cut in an altered pattern. Their experiments open up channels for familiar products to behave in unexpected ways and waste materials to find structural and formal roles in building assemblies.

Hilary Huckins-Weidner

Hilary Huckins-Weidner is exhibition coordinator and associate editor of *Material Acts*. She is a Los Angeles based editor, research and educator. Her research examines the political intersections of architecture, the environment, and media, focusing on tracing residues and legacies of development. She has taught in the Department of Urban and Environmental Studies at Loyola Marymount University, is on the Program Committee of architecture cultural non-profit Materials & Applications, and has contributed to numerous publications on topics of architecture, art, urbanism, and human rights.

Jennifer Johung

Jennifer Johung, Director of the Center for 21st Century Studies and Professor of Contemporary Art and Architectural History at the University of Wisconsin, Milwaukee, is an art historian who examines the intellectual and technical exchanges between life sciences and fields of art and architecture. Her recent book, *Vital Forms: Biological Art, Architecture, and the Dependencies of Life*, tracks the shifting ground of biology as a site of intervention by design disciplines and artistic practices.

Jia Yi Gu

Jia Yi Gu is co-curator and editor of *Material Acts*. She is an architectural scholar, curator, and designer with research interest in the history and politics of knowledge production, through the lens of media histories, cultural techniques, and material cultures. She is Assistant Professor in Architecture at Harvey Mudd College and co-director of the architecture research and design studio Spinagu. She develops exhibitions, texts, public programs and experimental projects.

Joar Nango

Joar Nango is an architect and artist whose work is rooted in Sápmi, the traditional Sámi territory covering the northern regions of Norway, Sweden, Finland, and the Kola Peninsula in Russia. In site-specific installations and zines, Nango brings Sámi construction traditions into contact with new media to challenge capitalist knowledge systems.

Katariina Träskelin

Katariina Träskelin is a Finnish photographer and 3d artist currently based in Singapore. She usually works in the fields of architecture, arts, and culture, and is particularly interested in exploring how to represent the feel of space in images. Katariina has a MA in photography from Aalto University's School of Art, Design, and Architecture.

Kate Yeh Chiu

Kate Yeh Chiu is co-curator and editor of *Materials Acts*. As a designer, editor, and arts organizer, Kate's work investigates material flows and labor conditions at the peripheries of architectural and cultural production. She is Executive Director of Materials & Applications, an editor-at-large with the *Avery Review*, faculty at the University of Southern California School of Architecture, and half of the collaborative design project yyyy-mm-dd.

Mae-Ling Lokko

Mae-Ling Lokko is an Assistant Professor at Yale School of Architecture whose scholarly work historicizes contemporary bio-based building techniques and design. In addition, at Yale's Center for Ecosystems in Architecture, she directs efforts to reshape policies that regulate the production and circulation of non-toxic, low-carbon materials.

Maru Garcia

Artist and chemist Maru Garcia works with living matter. Working between various vessels—a kitchen sink, a bathroom tub, custom-fabricated pools—Garcia tends to live symbiotic cultures, harvesting the resulting byproducts as disposable architectural skins and molds. Her research combines artistic and scientific modes of production, integrating laboratory and fieldwork practices with her background in plant chemistry and the pharmaceutical industry. Her work often transforms gallery and museum spaces into laboratory settings.

Natural Materials Lab

At the Natural Materials Lab in the Graduate School of Architecture, Planning, and Preservation (GSAPP) at Columbia University, Lola Ben-Alon teaches earthen building methods—both traditional techniques such as cob and clay plasters, as well as contemporary experimental possibilities like using natural material to 3D print architectural fibers. This hands-on pedagogical platform, which spans fabrication seminars to on-site testing, aims to recover and expand on techniques left behind by colonial structures and material industries of capitalism.

Omar Khan

Omar Khan is Professor and Head of the School of Architecture at Carnegie Mellon University whose research explores intelligence in materials through animated architectures. Integrating sensing equipment into flexible material systems, he scripts models of responsiveness that emulate homeostasis. This research suggests architectural protocols that modulate environmental fluctuations.

Post Rock

Post Rock, composed of Meredith Miller (Associate Professor, University of Michigan), Thom Moran (Associate Professor, University of Michigan), and Chris Humphrey (Lecturer, University of Michigan), is a research initiative that explores the use of waste plastics from

regional manufacturing, namely plastic from the Michigan auto industry, to create new building material, such as cladding components. In the course of their research, from speculative experiments to product development, the team has conducted material testing and evaluation in academic fabrication labs and commercial manufacturing facilities.

Rael San Fratello

Rael San Fratello, founded by architects Ronald Rael and Virginia San Fratello, utilizes the clay-heavy soil of their studio land in Colorado to experiment with 3D printing earthen building materials for the creation of adobe structures. The practice has tested these methods in the construction, maintenance, and eventual erosion of silos and hearths and other inhabitable structures.

Sara Inga Utsi Bongo

Sara Inga Utsi Bongo is a lecturer and practitioner working within the field of *duodji*, Sámi crafting methods. Drawing on her deep familiarity with reindeer herding, she prepares and makes traditional *duodji* of hide and fur from reindeer. In stitching a pair of cowskin boots with reindeer sinew or preparing hides, Utsi Bongo's work maintains, develops and transfers traditional craft knowledge of the Sámi peoples.

SOFTLAB

Directed by Felecia Davis, Associate Professor at the Stuckeman Center for Design Computing in the School of Architecture and Landscape Architecture at Pennsylvania State University, SOFTLAB is a research group that tests novel applications of textiles, from nano scale, to clothing, to architecture. The group's research is often initiated by translating diverse textile techniques, from knitting to felting, into shape grammars and computer code that are used as inputs to guide digital fabrication methods.

Soft Matters

Soft Matters is a research group at Ecole des Arts Décoratifs in Paris that focuses on developing flexible materials, from textiles to biological matter, to counteract the carbon cost of rigid and inanimate products, which remain dominant within the construction industry.

Strat Coffman

Strat Coffman, curatorial assistant and associate editor of *Material Acts*, is a designer and researcher who examines how design discourses, codes, and materials train the body, and how the embodied subject in turn agitates this training. They currently practice in Los Angeles and teach at the University of Southern California School of Architecture. They were the 2022–2024 Architecture Fellow at University of Michigan and a recipient of the 2024 Architectural League Prize.

Sutherlin Santo

Sutherlin Santo is a research workshop based in Portland, Oregon, operated by Garrett and Paul Sutherlin Santo that modifies digital fabrication technologies, such as 3D printing, to extrude and aggregate biological material into proto-architectural components. Their work re-engineers the life cycle of durable materials. Composed of biodegradable biogel, these materials participate in a circular economy, as they can be broken down through the biological process of decomposition.

Tag Christof

Tag Christof is a photographer working primarily from the road. He studied economics and industrial design at The New School and Central Saint Martins, and his research in architecture and collaborative design continues to inform his photographic work. His primary interests are the chaotic, contradictory beauty of America, planned obsolescence at every scale, and the unintended side effects of innovation. He lives between Los Angeles and Santa Fe and publishes, *motor—court*, a newsletter and podcast about American design.

Ye Rin Mok

Ye Rin Mok is a photographer based in Los Angeles. Her work spans architecture, interiors and portraits. In Korean, Ye Rin translates to "around art."

Yogiaman Tracy Design

Led by Christine Yogiaman and Kenneth Tracy, Yogiaman Tracy Design (YocY) is a research and design practice that augments craft traditions with contemporary fabrication methods to devise more robust roles for common material systems.

Zara Pfeifer

Zara Pfeifer is an artist based in Vienna and Berlin whose work is concerned with the social phenomena of large-scale infrastructure.

Zofia Trafas White

Zofia Trafas White is a London-based curator, researcher and exhibition-maker currently acting as Senior Curator at the Victoria and Albert Museum in London. Her work dissects the interface between design and science disciplines, specifically in the application and adaptation of scientific principles, such as biomimicry, within design fields.

Acknowledgments

This book is part of the curatorial research project *Material Acts: Experimentation in Architecture Design*, presented as both a publication and exhibition of the same name at Craft Contemporary in Los Angeles, CA, between September 28, 2024–January 5, 2025, as part of the regional initiative Getty PST ART: Art & Science Collide.

We are grateful for all the brilliant accomplices who joined us in this work over the past four years. Firstly, we are indebted to Suzanne Isken, former Executive Director of Craft Contemporary, for inviting us into this project in 2020. We thank Strat Coffman and Hilary Huckins-Weidner, our associates in curatorial and editorial thinking. Strat has been a thought partner since this project's conception, and their sharp insights are foundational. Much of the final phases of both the exhibition and publication would not have been possible without Hilary's keen and judicious hand, and we're so grateful to her for her work. Kate Rouhandeh has been an outstandingly patient managing editor, coaxing us with thoughtful and pragmatic calm. Becca Lofchie took text, images, and ideas and turned them into this beautiful volume, and we are lucky to have had her partnership in giving this project a graphic identity.

It has been a privilege and a dream to work with all of the contributors to this project. Each participant not only has been essential to the conceptual development and realization of both the exhibition and this book, but also plays a role in shifting today's culture of architecture and design toward deep thinking, care, and consideration of how we engage matter in our daily lives. We are fortunate to spend time with your practices, projects, and perspectives.

The team at Craft Contemporary deserves exemplary thanks: Rody N. Lopez for his leadership; Adrianne Toomey for finding abundance in times of scarcity; Frida Cano for the care she brings to curating; Joseph Baca for managing with ceaseless positivity; Andres Payan Estrada for his friendship and exuberant programming. Thanks also to Kate Zankowicz, Sherry Chen, Hana van der Steur, Erika Kieffer, Jules Kresnicka, Holly Jerger, Billie Rae Vinson, and Prima Jalichandra-Sakuntabhi for their support in the exhibition. We have become close affiliates with Craft Contemporary over the years—through this project and through cross-institutional collaborations in our individual appointments with Materials & Applications and the MAK Center for Art and Architecture. The landscape of small arts institutions in Los Angeles is dear to us, and our admiration and appreciation of Craft Contemporary has deepened and continues to expand with time.

We are also thrilled to gather and expand our project elsewhere in and beyond Los Angeles to greater publics. We thank Nick Axel at *e-flux architecture* for his collaboration commissioning and bringing the essays within this publication to an international audience. We are also incredibly grateful to Brett Steele and his team at the USC School of Architecture, who have been remarkably generous in their collaboration, hospitality, and sponsorship of *Material Acts: A Symposium*, held November 22–23, 2024. The ability to circulate our project through this book has been made possible by the Graham Foundation for Advanced Studies in the Fine Arts, where Sarah Herda, James Pike, and Carolyn Kelly have supported our careers and projects across institutions. We are ever grateful for their leadership in cultivating a culture of curiosity and critical thinking in architecture.

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