# Objects that Create Community

**Effects of 3D Printing and Distributed Manufacturing beyond Circular Economy**

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## Abstract

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Consistent with principles of Regenerative Development, which positions all aspects of human communities in balance with their local ecosystems, this paper argues that Additive Manufacturing (AM) has potential to alter global economic and manufacturing landscapes. Informing my practice-led research with a review of relevant scholarship I demonstrate how the convergence of 3D Printing with the Maker Movement can generate Circular Economy by fostering ecological awareness of material composition and overconsumption. By folding informal economies into the mainstream thereby strengthening community bonds, AM increases socioeconomic sustainability and creates opportunities for intervention in critical societal issues and associated pressures on resource and waste management. By modeling usage of open-source AM technology in the Global North, I identify barriers to its dissemination as an appropriate technology in the Global South. I outline strategies to circumvent obstacles to the disruption of global consumerism by shifting from underperforming Sustainable Design principles towards restorative Regenerative Development.



Keywords: Ceramic 3D Printing, 3D Printed, Additive Manufacturing, Democratized Manufacturing, Global Manufacturing, Circular Economy, Regenerative Development, Cradle to Cradle, Biomimicry, Up-Cycle, Upcycle, Blue Economy, Circular Craft, Alternative Economy, Appropriate Technology, Open Source, Hackerspace, Makerspace, FabLab, RepRap, Rapid Prototype

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## Dedicated to my mentor Ron Rivera (1922-2008)

Ron's work with Potters for Peace and with Filtron, an open-source ceramic water filter, embodied the work of his own mentors, Paulo Freire and Ivan Illich. He never forgot that those of us arbitrarily born into fortune and freedom owe it to those whose circumstances are not so lucky. Ron lived and died with an enthusiasm and spirit of generosity that continues to inspire me and so many others whom he has mentored along the way.

Ron never wavered from his mission to put appropriate technology in the hands of those who need it most. He taught me about his revolution and encouraged me to find my own. While Ron mentored me in my fieldwork, he taught me that through sheer enthusiasm I could seed community and create the momentum to bring on change. Because of you Ron, I continue to search for ways to use my passion in order to help others. Rest in peace old friend, your work continues.

# Preface

Recently when asked to define the term *Global South*, my response included harsh declarations about the North's afflictions of Individualism and Compulsive Consumption and the South's history of subsidizing these unsustainable paradigms at the cost of their own development. The inquirer and I were equally surprised by the bitterness of my response. I believe it is an indication of the frustration I feel regarding the injustices of our global economy and worse, my own complicity in it. As you read this document you may have concerns about a middle class, privileged woman of the Global North speaking about issues in the Global South. Be assured, I too am wary of this contradiction. If you are compelled to call out these doubts, I welcome an opportunity for reflection and growth.

Yet, it seems my whole life has led to conducting this research. I spent my youth dropping in and out of Canadian art schools during the late 80s and early 90s while intermittently working in Craft sectors of developing economies in Asia. I was searching for an explanation that might reconcile my perceptions of global socio/political injustice. I never did find them but eventually graduated with a BFA. I worked as a studio potter, instructor and technician for over a decade but became discouraged when finely crafted, well-designed, imported pottery undercut my prices and outsold me in the shops adjacent to my studio. I also became aware of the environmental damage caused by strip-mining clay; a so-called natural material. Disheartened, I refrained from making for a while and began working with an intentional community for adults with developmental delays while I pursued an interest in psychotherapy, ultimately training as an arts therapist. Moving into the realm of mental health I came to value the role of community to individual health and sought social justice work with non-governmental organizations (NGOs).

Around the turn of this century I began volunteering with an organization called Potters for Peace (PFP) and spent the next few years as an intern, alternating between living in the field with indigenous potters of Nicaragua and advocating for PFPs projects back home in Canada. This was also when I first became familiar with the concepts of *Open-Source* and *Appropriate Technology*. At that time PFP was developing a branch program that involved point-of-use, ceramic water filters which encouraged partnerships with indigenous potters and international NGOs. They helped pottery collectives across the globe access micro-enterprise funding while volunteers from PFP worked directly with the potters to pass on the Open-Source Appropriate Technology required to build the water filter factories and the filters themselves. I became deeply invested in the cause. What could be more important than helping people create clean water in their own communities? By 2004, I'd joined PFP's board of directors and after spending time in the field developing filter factories in Asia and the Americas I eventually co-founded the filter committee. Our tasks were to create a Best Practices manual and assess the viability of projects requesting support with implementing water filter micro-enterprises in their own communities. It was here that I learned about good intentions and their oft travelled roads to hell. I repeatedly witnessed well-meaning NGO's whose aid came in forms that superimposed their own values or priorities on their recipients. To be clear, I am not guiltless; I naively waded into these territories myself and remain reflective of my practice, learning from my own errors.

During this time I continued to offer technical support for potters in, what was then called, the Developing World. Taking leave from my private psychotherapy practice, I volunteered with various NGOs and a variety of artisans across the globe. The goal of any of these assignments was to offer technical support to indigenous craftspeople, discovering together what (if any) changes to their techniques could increase their livelihood or well-being. Modernization was never the goal and I was mindful of disrupting historical design influences and cultural priorities or rituals as well as social norms and mores bound up in craft tradition. I persistently reaffirmed the value of vernacular design elements with youth longing to break free of the constraints of tradition, enamored with a Hollywood image of "America." Such confusing times they were, as I was cautioned about corrupting impressionable participants with unsustainable images of an industrialized lifestyle while simultaneously being instructed that it was not my place suppress the evolution of culture so that visitors from industrialized regions could visit their so-called "quaint" lifestyle. It was a fine line to walk, fostering creativity, innovation and curiosity without overvaluing western methods or novel technologies. But I felt honored by the opportunities to work with makers and together we implemented techniques to augment the sustainability and profitability of their craft practices while remaining mindful that increased prosperity should not come at the expense of the environment or tradition. I always considered these trips a privilege and over the course of nearly two decades, I too prospered from these assignments. I got to work amongst folks in open air studios, while we discussed our lives and families to the best of our language abilities. I saw reciprocal benefits; I offered technical or ergonomic adjustments as I learned vernacular pottery techniques and absorbed some of those potters' ingenuity with the materials and tools at hand. I brought that spirit of resourcefulness, inventiveness and thrift home and applied it to my own pursuits; a most valuable skill that ran quite contrary to my art school training.

As a first generation Canadian, I am only one generation removed from the experience of hunger and religious persecution and am all too aware of the injustices and arbitrariness of socio/economic freedom. Still, I believe that by being born in the Global North I am the recipient of unearned advantages and opportunities and it is my duty to redistribute those benefits to others from whom they were taken. My own culture strongly values the role of "tzedakah." Though often mistranslated to mean "charity" I relate most to the biblical scholar Maimonides' interpretation that the highest form of tzedakah is to give or partner with another in such a way that will result in their own self-sufficiency (World Heritage Encyclopedia, 2018). Thus, I continue to volunteer for craft consultancies both in the Global North and South. Yet my pedagogy continues to evolve and as you read this thesis you will come to know my own struggle with the very idea of individual self-sufficiency vs. reliance on community. I remain unsure of how they may be reconciled but at least now I know that I might be asking the wrong question.

I am committed to an economic paradigm shift, requiring modifications on both sides of the global divide. What had been my informal style of train-the-trainer has become a formalized strategy of reciprocal information sharing and co-capacity building. I hope to leverage the democratization of manufacturing to foster international knowledge exchanges between community members, elders, educators and makers, where participants are charged with disseminating the information to their own people, according to their own pedagogy, beliefs and value systems. Who am I to address these complex issues? Again, I think this might be the wrong question. I have a little experience and a genuine desire to promote community health by fostering conversation. I hope you read this thesis with the knowledge that I too am aware of the problematic nature of charity, development work and transplanting information and even grapple with the inherent conflicts within the principles of tzedakah. When you have read this thesis, please feel free to engage me in conversation. Sam@3DPClay.ca

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## Glossary of Terms

**Additive Manufacturing (AM)** Fabrication processes that reproduce digital models by building up layers of material. Also known as rapid prototyping and 3D printing.

**Circular Economy (CE)** is a model of economy whereby resources are in continuous rotation as waste from one process becomes raw material for others (MacArthur 2012, 31).

**Distributed Manufacturing (DM)** the opposite of global or centralized manufacturing, requires liberally disseminated, small-scale factories (Srai, et al. 2016, 6917).

**Biomimicry** like Regenerative Design, looks to biological design to address ecological concerns. Although it considers the overlap of ecology with the built environment, generally does not place an equal emphasis on the social impact of design.

**Cradle to Cradle design (C2C),** as mapped out by McDonough and Braungart focuses on economic aspects of sustainable manufacturing. The authors reject the concept of developing eco-efficiencies to be applied to the take-make-waste model, calling it simply "less bad" (2002, 45). In *The Upcycle*, (2013) Braungart and McDonough further develop their theory, rejecting sustainable design as a mere slowing of environmental degradation by moving towards a holistic approach that encompasses environmental and economic concerns, calling it Upcycling. Although Braungart and McDonough allude to human health as a product of C2C design, it may be a likely bi-product of their design principles rather than a focused intention.

**DIT** Do-It-Together as opposed to DIY or Do-It-Yourself

**Fab Lab** "is the educational outreach component of MIT's Center for Bits and Atoms (CBA), an extension of its research into digital fabrication and computation. A Fab Lab is a technical prototyping platform for innovation and invention, providing stimulus for local entrepreneurship" (What is a Fab Lab? 2016).

**Open-Source Appropriate Technology (OSAT)** Technologies that are free to everyone to download and use, and "easily and economically put to use from resources readily available to local communities, whose needs they meet [9]. The technologies must also comply with environmental, cultural, economic, and educational resource constraints in the local community" (King, et al. 2014, 19).

**Performance Economy** as described by Walter Stahel, who also coined the phrase "cradle to cradle" in 1970 (Ellen MacArthur Foundation n.d.) is a variation of Circular Economy and "Goes a step further by selling goods (or molecules) as services through rent, lease and share business models (4,5). The manufacturer retains ownership of the product and its embodied resources and thus carries the responsibility for the costs of risks and waste. In addition to design and reuse, the performance economy focuses on solutions instead of products, and makes its profits from sufficiency, such as waste prevention" (Stahel 2016, 3).

**RecycleBot** a plastic extruder that creates 3-D printer filament from waste plastic and natural polymers" (Pearce, et al. 2017 np).

**Regenerative Development (RD)** "*Regenerative Development:* a system of technologies and strategies for generating the patterned whole system understanding of a place, and developing the strategic systemic thinking capacities, and the stakeholder engagement/commitment required to ensure regenerative design processes to achieve maximum systemic leverage and support, that is self-organizing and self- evolving" (Mang and Reed 2012, 2).

**Restorative Design** "Sometimes called restorative environmental design; a design system that combines returning "polluted, degraded or damaged sites back to a state of acceptable health through human intervention" [10] with biophiliac designs that reconnect people to nature" (Mang and Reed 2012, 2).

**Regenerative Design** "A system of technologies and strategies, based on an understanding of the inner working of ecosystems that generates designs to regenerate rather than deplete underlying life support systems and resources within socio-ecological wholes" (Mang and Reed 2012, 2).

**Reproducible Rapid Prototyper Machines (RepRap)** "The word RepRap is short for **Rep**licating **Rap**id-prototyper […] It is the practical self-copying 3D printer […] a self-replicating machine […] Following the principles of the Free Software Movement we are distributing the RepRap machine at no cost to everyone under an open source license" (Bowyer 2005).

**Service design** focusses on the social aspect of design with its emphasis on Redistributed Manufacturing (Mazzarella, Escobar-Tello and Mitchell 2016, 13), Systemic Relationships (2016, 15) and their inherent impact on individual and community well-being. This field encompasses sustainable entrepreneurship and social enterprise (Belz and Binder 2017) with its divergent focus on the human, sociological principle of the tri-polar model of sustainable design.

**Sustainable Design (SD)** focusses primarily on "minimizing damage to the environment and human health, and using resources more efficiently; in effect, slowing down the degradation of earth's natural systems" (Mang and Reed 2012, 3).

**Up-cycle** is a process that can slow down the filling of dumpsites with obsolete products by reusing post-consumer waste to make new objects without recycling or separation of components.

**Upcycle** a term related to Circular economy is the reuse of an object as is, without recycling or remanufacturing, cascading it down toward its eventual biodegradation or reclamation of its non-biodegradable/technical nutrients.

## Introduction

I have long wondered about the relationships between consumption, distribution, collaboration and community. The interdisciplinary nature of my career history as a studio ceramist, Global South craft consultant and as an arts-based psychotherapist, have posed opportunities for work at the intersections of art and mental health and craft and physical health. Recently, I became curious about the intersection of design and community health. I came to graduate school to discover if I could design objects that could create community. Through my academic and studio-led research, I have found my answer–no, not exactly. Instead, I came to understand that objects cannot *create* community because objects are *part of* a community. I have gleaned that in order for global health to thrive in the Anthropocene era, humans must stop privileging our own existence over that of other beings and recognize that not just every*one*, but also every*thing* is part of our community.

Relying on my history of consulting with indigenous craftspeople in Asia and the Americas, I had a general understanding of rubbish storage conditions in those specific areas of the Global South. My studio research initially focused on applying Sustainable Design principles to Up-cycled objects from post-consumer waste likely to be found in urban or rural areas. (Because terminology for Up-cycling is not universally consistent, for the remainder of this paper I will use the terms in the following manner. Up-cycling is a process that can slow the progress of filling dumpsites with obsolete products by reusing post-consumer waste to make new objects. However, Upcycling, without the hyphen, involves the reuse of an object as is, without recycling or remanufacturing, cascading it down toward its eventual bio-degradation or reclamation of its non-organic materials.) I set out to locate what types of value could be generated for Global South artisans using post-consumer or agricultural refuse as raw craft material. However, as my research progressed, I was no longer convinced of the environmental sustainability of Up-cycling as a design practice. Moreover, I was skeptical of Sustainable Design theory's lack of focus on wider societal iniquities created by global manufacturing. Thus, I learned that long-term, interdisciplinary solutions to societal and environmental problems related to global manufacturing would only be possible in an alternative economic model.

This line of enquiry led me to explore the Maker Movement, Circular Economy and the burgeoning field of Additive Manufacturing. Still intent on designing objects that create community, I eschewed the theoretical framework of Sustainable Design and adopted a Transformative, practice-led research methodology – namely a post-disciplinary, reflexive research practice where non-predictive enquiry, unbound by disciplinary borders, can lead to radical challenges in existing knowledge (Sullivan 2010, 109-112). In order to develop practical knowledge by simulating the maker's experience in both the Global North and South, my studio-led research included first-hand exploration of these two fabrication techniques. My academic research explored how the injection of Upcycling and Additive Manufacturing into both developed and developing economies might eliminate specious Sustainable Design practices in manufacturing and lead to economic models that embrace Regenerative Development principles.

Utilizing Upcycling and Additive Manufacturing as case studies, I demonstrate how these fabrication practices can redistribute manufacturing both in the Global North and South. Initially, using extant literature and my own studio research, I examine how value can be generated for Global South artisans by employing the Sustainable Design practice of Up-cycling post-consumer or agricultural waste. I argue that artisans benefit financially from using free or low-cost waste as raw material and that artisans benefit socially by creating closed loop communities with non-monetary and in-kind benefits. I also argue that while there is some diversion of waste, the greater benefit provided by the artisanal products is in their ability to generate awareness regarding the unsustainable premise of a globalized manufacturing economy. By embracing and applying the principles of Circular Economy and Regenerative Development, my research then shifts to focus on 21st century makers across the globe and the impact we can have on disrupting the precarious take-make-waste manufacturing paradigm.

My research thus synthesizes scholarship and practice from the fields of Design, Development Economics and the Social Sciences to examine the relationship between the Maker Movement and Alternative Economic approaches. Specifically, I question in what ways do Additive Manufacturing and Up-cycling fabrication practices contribute to models of an alternative economy? How can these fabrication methods, taken as Regenerative Development initiatives, benefit makers in the Global South? Finally I explore, what, if any, role can the Maker Movement have on fostering community? I hope to be able to share these findings with policy makers and program developers in the Global North and South.

## Situating Theories of Alternative Economies and Design

I begin by reviewing literature on alternative economies to provide the background for my subsequent discussions of the Circular Economy, Sustainable Design and Regenerative Development. Specifically, I focus on explorations of Circular Economy [1] in the Global South as a component of Regenerative Development using the lenses of Up-cycling and Additive Manufacturing. I acknowledge the many discourses defining the principles and components of alternative economies;[2] however, in this review, I will focus only on Circular Economy based on ecological principles of circulation of materials.[3] Among the arguments for and against Circular Economy, I will locate a parallel discourse on Sustainable Design (SD) theories that will eventually lead to analysis of the discourse encompassing Regenerative Development. I will then review the literature regarding Up-cycling and Additive Manufacturing (AM) in an effort to assess the extent to which they may contribute to the formation of Circular Economy (CE), as a component of Regenerative Development (RD) in the Global South.

## Alternative Economy

Alternative economies are alternative to what? Emily Kawano, an economist committed to social justice, answers this question when she outlines that the mainstream economy in the USA is based on either Keynesian or Neoliberal principles, which are both in service to a capitalist economy (2009, 12). She continues that, “Homo economicus is a rational, calculating, self interested [Sic] fellow who seeks the greatest payoff for the least amount of effort or cost. His calculations are made from the perspective of himself as an individual, not on the basis of the larger community, environment, nation, or world" (2009, 14). Design historian and urban waste theorist, Robert Crocker, agrees that systems created by these "Homo economicus" fellows are doomed to create and recreate economic meltdowns like that which occurred globally in 2008 (2015, 85). Kawano suggests instead, that in a solidarity economy, "We should take our cue not only from the Darwinian notion of survival of the fittest, but just as much so from ecological models of interdependent symbiosis and cooperation" (2009, 15). Kawano's critique of the current US capitalist economy focusses on issues created by the second industrial revolution.

In contrast to Kawano's (2009) argument, Susan Strasser, a historian of consumer culture, points instead to global consumerism as a significant cause for current economic and ecological uncertainty and thoroughly describes village-based capitalism as its predecessor (2003). Strasser indicates that after the industrial revolution, female homemakers were largely the targets of the advertising campaigns required to shift these custodians towards consumerism (2003, 386). She argues, that by enticing women away from the "drudgery" of housework and toward more time-saving "conveniences" (2003, 384) these campaigns implied that the production, conservation and reuse of household items were unworthy uses of a modern woman's time (2003, 382). While release from household maintenance was a welcome shift, when conflated with ideals of prudency and conservation of possessions, it also contributed to overconsumption causing a significant ecological cost (2003, 379-388). In this light, Crocker develops an argument that draws on Strasser's position, describing an earlier "home-based regime of use and disposal involving extensive reliance on repair and recycling, where most household waste was burnt, often in the kitchen stove, and ash, bone and human wastes collected for reuse for local industries and agriculture." (Strasser 2003 cited by Crocker 2015, 83). Crocker continues that this earlier age – the era of Custodial Consumption – "was a time when consumption was widely understood as providing 'access' to more essential goods and services, and not the pursuit of luxury or 'excess' for self-transformation and self-expression, as is now more common" (Crocker 2015, 83). Strasser acknowledges that the arrival of industrialization was and continues to be staggered across the globe (2003, 379), but notes cross-cultural similarities which privilege convenience over thriftiness and that, "as consumers came to depend on complex goods from distant sources, they came to understand less about how things were made, how they worked, how they could be fixed" (2003, 381). She concludes that consumer culture and the linear economy are unsustainable and must end (2003, 391).

Focused on accelerating the transition to CE, the Ellen McArthur Foundation similarly positions itself against capital-maximization models in favour of a socially responsible stewardship of materials. In "*Towards the Circular Economy*" (2012), the authors advocate for economic reform, endorsing the merits of circularity whereby resources are in continuous rotation as waste from one process becomes raw material for others. They explain that the basic principles of CE include designing out waste, building resilience through diversity, relying on renewable energy, thinking in systems and generally accepting that waste is food (2012, 31). In this vein, Walter Stahel, a long-time policy consultant for European economic reform, adds service contracts to Performance Economy[4]. His model of CE, allows consumers to rent the use of products rather than own them arguing that “The reprocessing of goods and materials generates jobs and saves energy while reducing resource consumption and waste” (2016, 3).

Yet, is CE a viable alternative to Kawano’s rational homo economicus? Critiques of CE point out that rather than small-scale, local applications of Custodial Consumers’ principles of yore, these approaches are often based on global applications. Notably, Costas Velis, a respected academic and expert in resource recovery, remarks on the iniquities of using unregulated facilities in the Global South to reclaim materials from waste generated in the Global North as is the current model (2015, 390). Indeed, other scholars agree, warning that this hybrid of CE and global consumerism runs the risk of perpetuating the existing economic iniquities. For example, Joanne Linnay, a business analyst and field researcher, notes in her case study of recycling and social entrepreneurship that, “Classifications and typologies that explore finance and mission relationship and the type of capital leveraged are unable to integrate nuances, including power dynamics, social justice, and contextual variables” (2013, 94) and that recycling-based social enterprise “must engage in a reflective dialogue that integrates discourses such as social justice, gender analysis, power dynamics, race and class” (2013, 94).

Neil Maycroft, a scholar of design and material culture, also speaks of the potential perils of CE on a global scale. He cites a design model, Design for Disassembly (DfD), which allows for consumer products to be easily disassembled so that components can be reused entirely within new products. Ideally, once a manufacturer is committed to this process, it may generate objects that are easily disassembled and separated into their various nutrient components which can in turn, be easily be reused (2000, 147). However, Maycroft warns that instead of insisting that manufacturers be held responsible for waste generated by their products, extra expenses associated with DfD, might be offloaded to the consumer in the form of mandated home disassembly (2000, 147). By protecting profit margins, this system could perpetuate the inequitable economic and power status quo.[5] Similarly, Maycroft (2000, 146) cautions that additional costs could be associated with Stahel's Performance Economy theory of design. As Maycroft explains, "Surrounding a product with a number of service options, or perhaps even requirements on the part of the consumer, can be viewed as not only increasing consumption (of services at least) but also as a means of tying consumers ever closer to the institutions, regulations and financial imperatives that govern consumption" (2000, 146).

Finally, Maycroft also warns of the dangers of small-scale, local recycling creating a glut of product-specific recycling depots. He outlines that, "The ecological benefits of recycling could be easily undermined by the energy input and pollution output that maintaining multiple facilities of this kind entails" (2000, 148). He continues his skepticism of recycling as a sustainable practice by pointing out the transport costs of central recycling depots or producer responsibility laws which require products to be recycled by the original manufacturer, increasing shipping distances and again outweighing any ecological benefit of recycling (2000, 148). Maycroft's arguments do not necessarily dispute that CE's principles are potentially viable goals, only that existing global power and wealth dynamics could corrupt the potential environmental and economic savings when applied on a worldwide scale.

Taking these concerns one step further, environmental historian Carl Zimring, points out that recycling or down-cycling may act as a salve on consumerist guilt, making it all too easy for citizens of the Global North to turn a blind eye towards waste and a material's next step in its lifecycle (2017, 2). Velis also argues that CE requires smaller communities and tighter loops of raw materials in which manufacturing and distribution remain local enough for accountability and that without significant education and regulation, when recycling is scaled to a global scope, social iniquities are a likely outcome (2015, 391). Within this broad contextual background, in the following sections I use my practice-led research as case study to demonstrate how the Maker Movement, tied to Up-cycling and AM, embraces a circular economic model and provides an opportunity to create an alternative economy practice.

## Sustainable Design

As discussions of CE are rooted within the discourse of Sustainable Design, it is important to position the various frameworks of circularity within this context.[6] Design historian, Pauline Madge argues that since the 1980s there have been many waves of SD creating "a deep division within the environmental Movement between those who advocated a radical rejection of the status quo, […] and the lighter green idea of modifying existing institutions and practices" (1997, 46). She illustrates how the Green design of the

80's gave way to the Eco-design of the 1990's which in turn begat SD around the turn of the 21st century (1997, 44). By 2002, light green SD had become part of the mainstream vernacular shaping corporate and government policy. Ultimately, according to design education historian Alain Findeli, although SD is nobly based on either a tri-polar framework, Economics/Environment/Equity or the triple bottom line, Profit/Planet/People (2008, 304)[7], its principles, are "spelled out like a gospel [or] mantra" (2008, 302) rather than through enforceable design theory. To clarify, Findeli argues that SD's ambiguous mandate does not clearly define how its lofty ideals will be applied in practice and the lack of re-education or enforcement doomed many projects to failure despite their stakeholders' noble intentions (2008, 303). Unfortunately, ambiguous principles of light green SD and lack of compliance enforcement have more recently resulted in "greenwashing" or deceitful claims of ecological safety that became ubiquitous in North American markets (TerraChoice Group 2009, 1).

Meanwhile, a darker green faction of SD was taking root. Madge noted that SD, while certainly headed in the right direction, was inherently problematic. By encouraging the designer to aim for more efficient consumption to decrease environmental impact, light green popular SD sets the bar too low for true sustainability (Madge 1997, 56). As such, light green SD positions designers as enablers of overconsumption and complicit facilitators of global manufacturing practices. However as early as 1997, Madge pointed out that theorists such as Vance Packard (1960), Buckminster Fuller (1969), Stewart Brand (1970) and James Lovelock (1987) had already argued for many of the basic principles of

Green or Eco-friendly design theories (1997, 44). Referring to environmental concerns in design,[8] Madge notes

> These issues may be new to design in the 1990s but, within the environmental literature, there has been a constant discussion since the 1960s of the extent to which an ecological world-view represents a new paradigm requiring a fundamental challenge to industrial society, or merely a minor modification of existing values and practices, and a debate over the degree of change required to overcome the current ecological crisis" *(1997, 54)*.

Victor Margolin, who was amongst the earliest and most influential design theorists, began to see the limitations of SD theories in relationship to material. He refers to the "expansion model and the equilibrium model" (1998, 85) variously to denote the fracture in SD principals. In dialogue with Madge's (1997) critique of Eco-design, Margolin observed that expansion model SD theories neglected to use social critics' extensive concerns of the take-make-waste model and continue to situate themselves within the capitalist consumerist model (1998, 88). Margolin was one of many scholars (see for example Bonsiepe, 1992, Durning, 1992, Fry, 1994 and Manzini, 1994) who identified that

> Older models of practice are not working. Many new concepts such as design for disassembly, life cycle design and design with recycled materials, are responses to this situation, but most of these concepts are aimed at reforming consumer culture rather contributing to a new vision of professional practice (Margolin 1998, 88).

Although these theorists were among many who were considered radicals in their day (Margolin 1998, 85), we shall see that principles of their equilibrium model form a lineage that can be traced from the 1990's to contemporary design theories including Regenerative Development.

Margolin suggests, "The primary question for the design professions thus becomes not what new products to make, but how to reinvent design culture so that worthwhile projects are more clearly identified and likely to be realized"(1998, 86). He surmised that the Rio Accord in 1992 and its subsequent report outlined a roadmap of SD principles for the many signatory countries, spawning the "culture of sustainability" (1998, 86). Indeed, decades earlier than Findeli (2008), Margolin had already called out the lack of mechanism to hold the participating governments accountable to the Rio accord, and that efforts to implement sustainable practices had become a conceptual goal rather than a practical application (1998, 85). Corporate Sustainability educators Magali Delmas and Vanessa Burban illustrate how this same ambiguity of the expansion model and its "lax and uncertain regulation is a key driver of greenwashing" (2011, 65) whereby unscrupulous firms engage in "misleading consumers regarding the environmental practices of a company or the environmental benefits of a product or service" (2011, 64).

Perhaps inspired by observations made by Margolin and noted colleagues, Eric Nay, an innovative architect and design educator, calls for revolutionary alterations to Design Education. Nay exposes impotent SD principals, which fail to address fundamental, socio-economic imbalances by narrow-mindedly privileging "green" issues (2009, 37). In a more recent commentary on design theory in education, Nay expands the topic suggesting that, "The language we use in discussing sustainability is largely a byproduct of earlier initiatives that are steeped in the goals of universal capitalism, growth measurements determined by GDP's and other purely monetary metrics that have not created an open framework that combines both the art and the science of law tempered by a broad shroud of humanities- based qualitative understanding tools" (2013, 112). Nay concludes that design educators have a responsibility to arm the next generation of designers with criticality, so that they may focus less on stylization and more on problematization (2013, 113).

Scholars Packard (1960) and Brand (1970) have been warning of such a misuse of materials for over half a century leading design theorists Papanek (1972), Margolin and Buchanan (1996) to be concerned that SD may be firmly ensconced within the current global consumerist, economic and anthropocentric model; they thus warn that SD's environmentally friendly lingo continues to inspire false hope that our future will not require radical change in how humans think and consume on Earth. I had an opportunity to learn this empirically when I optimistically integrated Up-cycling into my studio practice in hope of finding sustainable uses for post-consumer waste. However, I developed doubts about this method of reducing consumption as I recognized that Up-cycling plastic is an example of McDonough and Braungart's "less bad" (2002, 45) approach to design thinking. I soon learned that "Practices in sustainable or green design have focused primarily on minimizing damage to the environment and human health, and using resources more efficiently; in effect, slowing down the degradation of earth's natural systems" (Mang and Reed 2012, 3). Thus, I went in search of more substantial uses of my capacities as a designer. Little did I know that in my studio journey, I would wallow in oceans of plastic, harvest a sheaf of pineapple paper and virtually remodel my craft in the dynamic field of Additive Manufacturing.

Considering that overstating a product's environmental value, or greenwashing, is just one of the many problematic by-products of SD within the take-make-waste model, what are design's alternatives? We shall see that when aiming instead for a CE, the designer accounts for the lifecycle of a product from start to finish to *start again* – Take-Make-Use-*Return*. Thus, as a counterpoint to contemporary SD philosophies, noting nature's tendency toward circularity, in 1996, John Tilman Lyle authored a new design method called Regenerative Design (1996). Although its framework is more circular than sustainable, Regenerative Design is rooted in ecology and it too does not focus heavily on the designer's role in sociological well-being. According to Mang and Reed, founders of the Regenesis Group, Regenerative Design lacks the interdisciplinarity required to solve complex problems caused by a "fractured relationship between people and the living web of nature" (2012, 28). This understanding prompted them to advance a new schema called Regenerative Development (RD) – a methodology that grounds Lyle's Regenerative Design principles in an interdisciplinary framework (2011, 28). Mang and Reed argue that,

> Regenerative Development works at the intersection of understanding and intention. It enables people to understand themselves and the places where they live as complex, evolving, living systems. It then builds the political will and the systemic thinking capabilities that are required to design and create new ways of living in harmony with those living systems. (2012, 16)

Rather than a straightforward design system, RD is a methodology that seeks to change the current economic paradigm. It challenges the underlying premise of societal structure and hierarchy and the complexity of our current sustainability issues. RD suggests that an entirely new approach to design thinking is required and most importantly, must not be limited to the human built environment (Mang and Reed 2012, 3).

Parallel to this inquiry into design theory, I began investigating practical applications of revalorizing waste. Initially, the results of using post-consumer garbage in the studio were mixed. Though I could generate marketable objects, I was disappointed by my minimal consumption of waste. Inspired to investigate further, I began to imagine how waste products could be funneled through multiple levels of manufacturing and wondered how this could affect the people who trafficked in it. Might reclaiming discarded by-products be a way of drawing individuals together so that they worked in unison instead of in parallel? Indeed, was CE simply a euphemism for community? I simultaneously investigated uses for agricultural waste and theories of RD while an exciting notion took root in my thoughts. By reusing waste, might I finally design an object that would create community?

Utilizing Up-cycling and Additive Manufacturing as case studies, the following is an analysis of Circular Economy as a component of Regenerative Development. Both my didactic and studio research into reusing waste in the Global South reveal that Up-cycling is a stop-gap measure that offers temporary diversions of waste already generated by the global consumerist economy. By contrast, I will demonstrate that Upcycling is a long-term solution regarding material stewardship and if tied to AM, presents opportunities to create entirely new approaches to fabrication and consumption.

## Up-cycling: a case study of Regenerative Development

Up-cycling[9] continues the story that began with *Spaceship Earth* (Fuller 1969), *Whole Earth Catalogue* (Brand 1970) and *Gaia Hypothesis* (Lovelock 1987). These early publications on the perils of waste foretold our current predicament of overflowing waste piles and diminishing stores of precious materials. We have established that with their critiques of the state of product design, Papanek (1985) and Margolin (1998), were close on their heels. In this section I will illustrate how McDonough and Braungart (2002) (2013), Pauli (2010) and the Regenesis Group (Mang and Reed 2011) are amongst design theorists who continue to carry the torch of responsible design centered on the judicious use of materials on Fuller's *Spaceship Earth*.

To Recycle, Up-cycle or Upcycle? The following survey of research demonstrates how this choice is based on the value associated with the original materials and the costs required to harvest them – challenges I also had to assess in my studio practice. As an example of revalorizing waste, I will investigate the value embedded in a cotton t-shirt by comparing efforts to recover its resources or retain its worth when considering the merits as Recycled cotton, Up-cycled cotton and Upcycled cotton. Recycled cotton grinds up the fabric and then spins the pulpy fiber into a new yarn or thread. However, because these recycled fibres are degraded by the process, they must be blended with new fibres in order to maintain compositional strength and integrity. While compared to discarding the garment, this "down-cycling" certainly slows our t-shirt's journey to the landfill, ultimately it leads to the same waste-producing outcome (McDonough and Braungart 2002, 57).

In her study of recycled Saris in India, Lucy Norris, an anthropologist who specializes in life-cycle analysis of textiles, offers tangible proof of this tendency to create inferior products by recycling or more accurately down-cycling textiles (2012). For example, Norris contrasts the virtuous Global North narrative of donating clothing to the poor with the reality of the resultant quality of a woolen aid blanket woven from the re-spun, recycled wool fibres of those donated clothes. She notes the blanket's inferiority compared to those made of new wool and its inability to meet environmental or ethical production standards (2012, 390). Norris' argument for a moral economy exposes the ethical concerns of textile recycling and relates it to Maycroft's and Velis' concerns regarding the ethics of dry materials recovery noted earlier (2012, 391).[10] Norris too argues for a smaller materials loop to realize the potential of CE practices. She suggests that consumers who donate their largely underutilized clothing may glean false absolution from their participation in Global Manufacturing's take-make-waste economy. Norris continues that by shrinking the distribution chain, donors may engage with suppliers, manufacturers, distributors and waste collectors and thus witness the true impact of overconsumption (2012, 393).[11]

On the other hand, Up-cycled cotton is created when, instead of grinding and spinning existing clothing or textiles into inferior threads, discarded fabric is refashioned into new products from their current textile format. As in days of Custodial Consumption, our cotton t-shirt example may become a bohemian handbag, a mini-skirt, diaper or a rag-rug before eventually becoming trash.[12] As we shall see, this downward cascade resembles Upcycling in that waste is diverted from landfill and reused. However, many current objects in the built environment were produced in the take-make-waste model and often contain hybrid materials – mixtures of both compostable biological substances with synthetic technical elements (McDonough and Braungart 2002, 105-110). McDonough and Braungart refer to these hybrid materials as "unmarketables" (2002, 116) as they are often toxic and cannot be safely recirculated in the technical sphere or the biosphere. The authors suggest that instead of becoming waste, destined to languish in landfills, they can be stored in "parking lots" (2002, 117) maintained by the original manufacturer, awaiting detoxification or re-use.[13] Since, currently, this is not a requirement for most manufacturers, just as Packard (1960) and others predicted half a century ago, we have inevitably come to an impasse with the take-make-waste manufacturing model. Fortunately, a number of design theorists did heed early warnings and have developed methodologies that could pose solutions for these concerns.

I do not wish to discard the value of Up-cycling entirely. Many design theorists agree that regardless of its stopgap nature, financial gains are possible for makers who harvest waste (see for example Maycroft 2000, 153 or Sung 2105, 31). Gunter Pauli, an entrepreneur committed to developing circular business models, compiled a report on extant commerce that demonstrates how profit margins increase if raw materials are easily retrievable and low-cost or free (2010). He adds a critique of current business education that fails to teach this obvious reality as a core-competency (2015, 199). As demonstrated by my own studio practice, makers could clearly benefit financially from using free waste as raw material just as I was able to fabricate marketable wares requiring minimal investment in supplies by utilizing free materials including discarded plastic bags and bottles, floral offcuts and juice pulp.

Furthermore, Lynne Milgram, a noted ethnographer with considerable fieldwork experience in the Global South, observes that Up-cycling creates advantages less obvious than financial gains. She has identified that Up-cycling makers may also benefit socially by creating closed loop communities with non-monetary and in-kind benefits. Milgram notes that these diverse connections may create new manufacturing supply chains, artisan cooperatives or other alliances where none existed before (2010, 81). In fact, Bruce Metcalf, a noted craft historian, suggests that these new networks of Do-it-together (DIT) makers, informal economy suppliers and local customers create a facsimile of CE, despite the initial influx of imported waste supplies (2008, 2). Kawano agrees, that

> Zero waste's low-cost, simple solutions tend to strengthen our relationships within the community, support the local economy, and be good to Mother Nature […] Sharing and joint problem-solving, not money and material goods, become the currency of exchange (2009, 202).

I thought about how this might apply to waste pickers, vulnerable members of marginalized informal economies who harvest garbage to generate income.[14] Milgram suggests that Up-cycling provides waste pickers a legitimate livelihood allowing them to be brought back into manufacturing supply chains and consequently return to the fold of a socially acceptable formal economy (2010, 79).

Sung and her co-authors, design researchers whose work focusses on the social, environmental and economic impact of Up-cycling, have shown that these smaller loops of commodity chains do not just create stronger connections between suppliers and makers. The networks also create a stronger sense of accountability for materials including those contained in imported, cheaply manufactured exemplars of the take-make-waste paradigm (Sung et al. 2014, 240). Global business and marketing scholars Sahni et al. add that consumers assign more value to Up-cycled objects. They argue that because consumers create a narrative regarding the object's journey and the artisan's perceived ingenuity, they tend to discard or replace Up-cycled objects less frequently (2015, 335). Once revalorized, diverting these hybrid materials from landfill or incineration does temporarily diminish their carbon and water footprints, be it pop bottles or pineapples (Pauli 2015, 135-137). This too became evident in my studio practice as colleagues handled my jewelry and paper products with great care despite the fact that they were made out of what had recently been labelled as garbage. I could see that I was edging closer to designing objects that create community, but I was missing one crucial element. My journey to locate the connection between Design and Community necessitated a shift in my research from Up-cycling to Upcycling.

## Upcycling as a Component of Regenerative Development

Following is a review of literature that demonstrates how Upcycling, as an element of Circular Economy, is also key to an entirely new paradigm of material stewardship, Regenerative Development. McDonough and Braungart are among the practitioners who initially popularised the *Cradle-to-Cradle* model of design (2002) and embraced the principles of *The Upcycle* (2013) within their practices. Their model advocates for designs of the built environment to use materials in their existing forms, naturally breaking themselves down by cascading through different industries and functions on their way back to becoming simple bio or technical nutrients (2013, 45). Let us return to the example of the lifecycle of a cotton t-shirt by considering the Ellen McArthur Foundation's explanation of Upcycling,

> As when cotton clothing is reused first as second-hand apparel, then crosses to the furniture industry as fibre-fill in upholstery, and the fibre-fill is later reused in stone wool insulation for construction—in each case substituting for an inflow of virgin materials into the economy—before the cotton fibres are safely returned to the biosphere (2012, 7).

Scholars agree that accounting for the bulk of its own needs by locally cultivating, fabricating, distributing, consuming and reclaiming nutrients required for local manufacturing is an essential component of a thriving, sustainable economy (McDonough and Braungart 2013; Pauli 2015, 52-59).

Challenging the reduce/reuse/recycle model, McDonough suggests that planned obsolescence or overconsumption are not particularly concerning issues. Instead, he suggests that a breakdown occurs when there is no plan for the obsolescent object following consumer use, particularly when materials are hybridized in such a manner that they cannot be recovered (2016, 6). McDonough and Braungart's metaphor of a cherry tree hinges on the tree's own overly fruitful nature that continuously circulates its own nutrients to survive (2002, 72). They suggest that by utilizing a *Cradle-to-Cradle* design approach favouring renewable energy and the recirculation of biological and technical nutrients, environmental concerns can be addressed organically and overproduction or overconsumption could be curtailed.

Although in *The Blue Economy*, (2010) Pauli similarly focuses on examples of businesses thriving while operating within this model of circular consumption, in a later publication, *Version 2.0* (2015), Pauli clarifies that simple circularity of materials is an insufficient intervention in what he refers to as the MBA “make more money” business model (2015, 48). Pauli’s broadened focus more closely resembles principles of RD than simple Upcycling as it includes critique of public policy and observations regarding the social impact of the take-make-waste model. He notes that,

> We should evolve from the logic of economies of scale and cost cutting towards a society that uses what is has, responds first to basic needs of all, circulates the newly gained purchasing power in the local communities and generates capital, especially social capital and strengthens the Commons (2015, 48).

Like Pauli, RD authors, Mang and Reed encourage “human communities to co-evolve with the natural living systems they inhabit while continuously regenerating environments and cultures” (2012, 8). They add that design in this context must aim for pattern harmony, “whereby human communities, their activities and their biosphere” (2012, 21) are synchronized. Here too, my experience of paper-making from urban waste echoed the literature, in that I partnered with local merchants to form relationships and supply chains where none were previously existent. In describing my project to juice bar baristas, they often lamented the amount of pulp the juicers generated daily and were excited about the potential of reusing their waste by partnering with a social enterprise.

## Additive Manufacturing as a component of Regenerative Development

In order to provide a framework for my research on the impact of Additive Manufacturing on makers in the Global South, the following section investigates research that questions the means by which AM, popularly known as rapid prototyping or 3D printing,[15] could become a key component in the development of Circular Economy and Regenerative Development. I will explore scholars' suppositions that AM could lead to Distributed Manufacturing[16] which requires liberally disseminated, small-scale factories and can be considered the opposite of global or centralized manufacturing. Since AM processes and machinery are exceptionally well suited to these small fabrication venues it follows that AM may engender a closer relationship between consumers, materials and the production of goods, notable principles of Circular Economy. Thus, by enabling a shift away from global mass manufacturing towards small-scale, local workshops, accessible to both designers and makers, AM may become an integral component of RD.

Perhaps scholars' earlier warnings are being heeded and we have come to a peak in our unrestrained use and disposal of manufactured materials? Beginning with metals, this paradigm shift began at least as early as 1970 (Zimring 2017, 2) and currently a growing range of materials is being diverted or harvested from dumps including plastics, paper, compost and more recently, textiles (The City of Markham 2017, np). Zero waste policies of many municipalities are set as goals to ensure that, eventually, all consumer materials will be in complete circulation. As discussed, a RD community does just that, accounting for the bulk of its own needs by locally generating, distributing, using and reclaiming the nutrients required for manufacturing. Research has shown that just as the internet has democratized information sharing, so too has it democratized commercial transactions in the form of Block Chain, Fintech, Social Media Marketing platforms and online marketplaces (Park 2015, 270).[17] Suddenly, once passive consumers have become active members of a manufacturing landscape as makers, suppliers and vendors. Additive Manufacturing may have a parallel impact on traditional global supply chains.

Charter and Keiller's report on makerspaces and Circular Economy incorporates Anderson's findings on the subject in which the latter states that,

> The grassroots Maker Movement has been hailed as the new industrial revolution and has the potential to herald a new post-consumer, more sustainable approach to production and consumption through local peer production and the development of innovative products and services that are fit for purpose and longer-lasting (Anderson, 2012 quoted in Charter and Keiller 2014, 3).

Despeisse et al. similarly summarize fellow authors' findings concerning the positive implications of 3D printing with regards to Distributed Manufacturing (DM), "is its role in raising awareness about the impact of making things, as demonstrated by the rapidly emerging makerspace movement, and in changing perceptions about the quality of recycled materials" (2017, 12-13). Despeisse et al. add that the bespoke nature of AM design and production removes the need for economy of scale and focusses on economy of scope (2017, 17). Coupled with the accessibility of low-cost manufacturing machinery and the simplicity of production processes, AM creates opportunities to return to small production runs and local distribution, perhaps reducing overseas productions, if not rendering them unnecessary (Despeisse, et al. 2017, 5). As such, Jagjit Singh Srai, an associate researcher at Cambridge University, suggests that the new business landscape of AM and Fab Labs[18], that include open-source[19] technologies such as self-replicating 3D printers known as Reproducible Rapid Prototyper machines (RepRap) [20] and RecycleBots,[21] could shift manufacturing from global corporations to household or shared makerspaces. As a result, Srai et al assert that AM may create an opportunity for developing Circular Economy (2016, 17).[22]

To this end, Huang et al suggest that by participating in the manufacturing of goods, consumers may shift attitudes toward a circular approach to how they use materials and may press for more judicious use of raw materials in the goods they consume (2013, 1193). Similar to Up-cyclers, as knowledgeable producers themselves, consumers in an AM landscape can insist that objects be produced so that they are made of components of either biological or technical nutrients designed to be reclaimed and Upcycled (2013, 1194). Furthermore, because they utilize only the amount of materials needed for the product without the need for making molds or jigs, "AM technologies have the potential to reduce life-cycle material mass and energy consumed relative to conventional subtractive manufacturing techniques" (Huang, et al. 2013, 1195). Additionally, Despeisse et. al. suggest that environmental impact may be reduced by distributed materials markets and, "may incentivise the use of smaller concentrations of natural resources, leading to a reduction in transportation emissions" (2017, 5). They continue that, “Local, more flexible materials markets may be better suited to recycle highly distributed sources of consumer waste” (2017, 5) and reduce costs “stemming from the aggregation of waste by large-scale recycling facilities” (2017, 5).[23] M.A. Kreiger, a mechanical engineer analyzing 3D printing hardware, adds optimistically that,

> Combining the open-source distributed recycling of the RecycleBot with the distributed production of the RepRap combination systems would be the most economically beneficial for those interested in a complete distributed manufacturing process. This could even be accomplished on a household level. The RecycleBot could be used for disposing of a single household’s recycling, saving trips to return waste plastic and a stop for curbside collection. The RepRap could be used to print parts for simple household repairs and solutions (2014, 9).

Projecting the model one step further, Despeisse et al. posit that in this model, not only will raw material usage be scrutinized, but that Additive Manufacturing creates opportunity for new attitudes toward the lifecycle of manufactured products. They speculate that AM’s widespread usage could counter disposable and planned obsolescent design modes most prevalent in today’s mass manufacturing world (2017, 13). Regarding new modes of design the authors suggest that, “3DP has demonstrated high potential to enable product life extension through product redesign, repair, remanufacturing and upgradability” (2017, 13). Thus, these authors identify the use of local materials and smaller distribution areas as potential outcomes of distributive manufacturing, and that Additive Manufacturing may spur a natural shift toward Circular Economy. Furthermore, by combining the collective nature of makerspaces with a deeper understanding of manufacturing processes and heightened awareness of material usage, AM could also stimulate new modes of economy based not only on circularity of materials but also on shared skills, workspaces and tools. However, we shall also see that without deliberate intervention this is not necessarily so.

While providing some relief for landfills as discussed earlier, recirculating hybrid or environmentally detrimental materials, such as those used for some varieties of 3D printing filament, is a stop-gap measure. It has value as an interim step, so that at a minimum, manufacturers are recirculating existing plastic instead of generating more of these hybrid or toxic materials. However, as we have seen, because it relies on cheap, globally manufactured products, this form of Up-cycling lacks the basic concept of retaining nutrients in a closed geographical loop and therefore is untenable over the long term. None-the-less, scholars have found that AM processes do present opportunities within our current economic model. Hunt and Charter summarize usages of 3D printing in commerce where social enterprise companies create the filament (the "ink" used by 3D printers) from recycled plastic, (2016, 4) or use recycled plastic filament to print marketable products (2016, 7) and that benefits are increased significantly when global corporations 3D print finished products on an industrial scale and may minimize overproduction and material consumption by offering mass customization (2016, 7). In some cases, combining benefits, products are mass produced using 3D printed Up-cycled filament instead of virgin materials, further reducing carbon and water footprints (2016, 9).[24] While mindful of circular design principles, these companies are edging closer to Regenerative Development.

Klaus Schwab, a renowned entrepreneur and proclaimer of the fourth industrial revolution, notes that while these shifts toward democratization of manufacturing may have been developed in the Global North, widespread dissemination of AM and Upcycling could result in an economic revolution in the Global South (2016, 16). In this light, in a publication less than a decade old, engineering researcher and professor Joshua Pearce, an active champion of open-source technology, outlined potential challenges of the dissemination of RepRap in the Global South as an open-source appropriate technology (OSAT) (2010, 25). Even a mere four years later, in the context of salvaged High-Density Polyethylene (HDPE), Pearce and Krieger describe a more hopeful situation suggesting that, due to the low cost of the RepRap and RecycleBot, AM could be considered appropriate technology for the Global South. Kreiger et al. also argue that self-replicating printers and can be used to create spare parts to maintain existing hardware or to create new technologies, thus transporting the democratization of manufacturing to the Global South (2014, 10).

Similarly, Feeley, Pearce and asscociates examined the social impact of Up-cycling these polymers for 3D printing filament in the Global South (2014, 4). Citing the impact of RepRap and the RecycleBot on waste pickers, Feeley et al. outline opportunities in the areas of collecting, processing and selling waste plastic for filament and even manufacturing higher value products using their own RepRaps (2014, 4-5).[25] However, Feeley et al. warn that global ethical standards for recycled filament must be legislated to ensure that marginalized citizens of the Global South are not exploited and to ensure that they remain the beneficiaries of the resultant enterprises (2014, 9). In 2017, Despeisse et al. also warn of the dangers of perpetuating wasteful consumption within the current economic power structures. They suggest there is a limited window of opportunity for creating change in material usage that would lead to Circular Economy and warn that, “It is essential that CE principles are embedded into the new manufacturing system before the adoption of 3DP [AM] reaches a critical inflection point in which negative practices become entrenched” (Despeisse, et al. 2017, 14).[26]

In 2017, while in the thick of my own research, Pearce’s and Nilsiam’s position on RepRap’s viability in the Global South continues to evolve with the unprecedented rapid advancements in AM technology. They suggest that due to increased access to open-source software as well as the growing accessibility of 3D printers, projections for OSAT have actually been surpassed (2017, 2). Inspired by RepRap and RecycleBots, I could see now that 3D printing would provide the opportunity to design an object that creates community. Unlike implementing simple Up-cycling programs, these manufacturing shifts could produce significant savings of energy and material consumption, while providing less developed regions better access to much needed specialty manufactured goods. My only hesitation was my utter ignorance regarding all practical aspects of AM. The following sections outline my practice-led research into the likelihood of fostering RD in the Global South by deploying Up-cycling and AM fabrication processes.

## Studio Practice: Sustainable Design Case Studies

As we have seen, research indicates that Up-cycling only serves as a stop-gap measure between our current global manufacturing economy and potential alternative models of economic practice. Using imported, discarded goods as raw materials contradicts Regenerative Development's core principle of maintaining local circulation of biological or technical nutrients. In addition, we have seen the limitations of the ecological impact generated by artisan use of waste materials through Up-cycling (Maycroft 2000, 154). Scholars suggest that significant environmental impact through Up-cycling can only be achieved if large-scale manufacturing takes on a circular approach to design (Sung et al. 2015, 237). My own practice-led research findings echo these conclusions. In this section I will demonstrate how makers may benefit financially from using free or low-cost waste as raw material. My practice-led research, will also confirm that while Up-cycling does divert some materials from landfills, the greater benefit is provided by the awareness the artisanal products generate regarding the ecological realities of a globalized manufacturing economy.


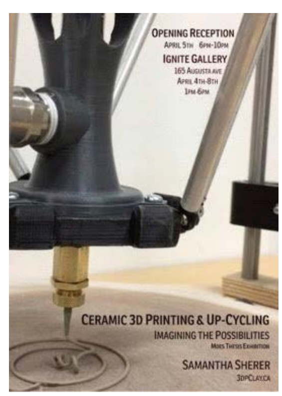


*Figure 1 Paper Making Manual, Sherer 2017*
*Figure 2 Exhibition Invitation, Sherer 2018*


*Figure 3  Polyethylene Bags, Sherer 2016*
*Figure 4  Knotting with Plarn, Sherer 2016*
*Figure 5  Making Plarn, Sherer 2016*

## Plarn

Initially, inspired by recent encounters on a volunteer consultancy with artisans in Honduras, I began by exploring the Up-cycling process with discarded, post-consumer plastics to create marketable objects. Produced from ribbons of polyethylene shopping bags, plarn is a yarn-like material used to weave, crochet or knit plastic textiles. Making the plarn itself is straightforward; the bags are simply sliced into equal width strips that are then looped together by hand. The resultant textiles can produce a wide range of products including upholstery, baskets, shoes and mats. Many existing social enterprises use plarn to create utilitarian products in the Global North or with indigenous artisans in the Global South.[27] My goal was to design a range of marketable products that could be created by waste-pickers with no prior skills and minimal tools. Pamela Harris Lawton, an innovative scholar and Art Educator noted that, waste pickers and university students benefitted mutually from their work in La Chureca, Nicaragua "creating items from refuse that could be sold, helping the community attain a measure of economic independence" (2014, 427). She explains that, "the projects we worked on together were tied to a *sense of place*, life in the trash dump and the materials at hand to transform a community" [emphasis original] (2014, 428). In fact, through transformational learning, Lawton's project in Nicaragua does more than simply elevate the income of one group of waste pickers; perhaps more importantly Lawton created an inter-continental creative community. Though I couldn't have articulated it in this stage of the research, connecting an international community through materials would eventually become my goal as well.

*Figure 6 Commercial and Improvised Knitting Tools, Sherer 2016*
*Figure 7 Commercial Hoop Knitting Plarn Sample, Sherer 2016*

Using online resources, I taught myself the technique of producing plarn and purchased a hoop knitting kit to explore a wide range of possibilities. I then set out to design products marketable to tourists that could be made simply by waste pickers and sold by street vendors or the rag pickers themselves. My process was iterative; I simplified the hoop knitting tools and varied the methods of textile fabrication including endeavors in knitting, weaving and knotting techniques. I also experimented with varying the type of plastic bag, the width of each strip and how the resultant yarn was spun. In each case, my goal was to make the process reproducible with no tools other than a knife and waste materials. For example, I substituted a variation of drop spindle spinning which I had observed in Peru, for the yarn twisting technique commonly employed in the Global North which requires a spinning wheel or sewing machine.

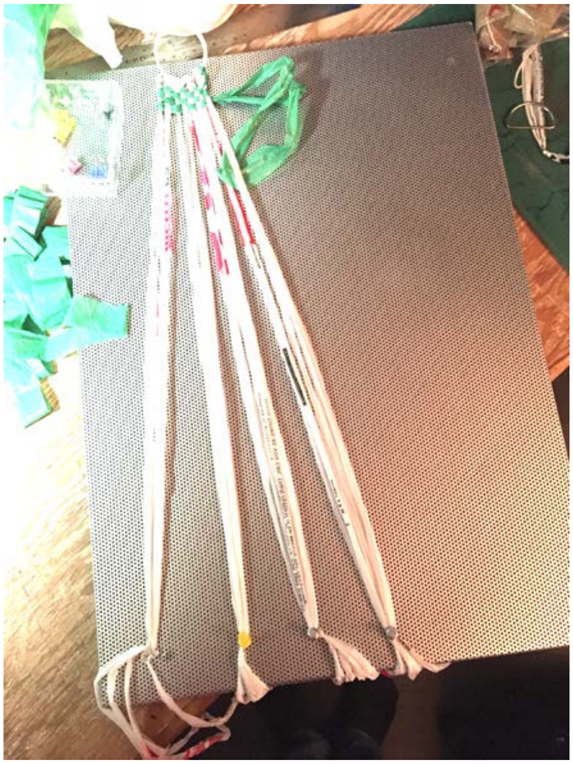

*Figure 8 Plarn weaving, Sherer 2016*
*Figure 9 Peruvian Woman drop spindle spinning, Sherer 2010*
*Figure 10 Belt, Plarn, Bottle Cap, Sherer 2016*

I experimented with material and technique allowing the plarn to inform me about its capacities and applications through its physical tendencies and limitations. Water bottle and yoga mat carriers were among my successful proofs of concept since they could be made simply using tools created from discarded plastic, scrap wood and nails. I was even able to use finger-knitting, a technique that can be taught within minutes, to create some of the objects. All parts of these carrier straps are made of Up-cycled plastic, readily available in rural or urban trash heaps, including plastic bags and tamper evident rings from plastic bottle caps. The maker requires only a knife or scissors to make these saleable objects. The availability of a multitude of colours and thicknesses of polyethylene shopping bags, as well as the variety of fabrication techniques allow the artisan to apply vernacular design elements to these modern objects. The resultant handmade souvenirs could appeal to tourists as both utilitarian objects and as mementos of exotic, colours and traditional patterns of the region. This practice addresses Bramston and Maycroft's observations that "There are multiple materials, in multiple forms that have the potential to be utilized for other purposes and yet the vast majority are disposed of" (2013, 128).

*Figure 11  Yoga Mat Carrier and Detail, Plarn, Sherer, 2016*


*Figure 12 Tools and PET Samples, Sherer, 2016*
*Figure 13 PET Jewellery Studio and Detail, Sherer 2016*

## PET

Following my exploration of potential uses of plastic bags, I experimented with different applications of Polyethylene Terephthalate plastic (PET) salvaged from water bottles and food packaging. Again, relying on my experience of working with artisans in Central America, I attempted to create marketable objects that could be made with everyday household tools and minimal skill. The artisans with whom I consulted in the Global South often reported that their customers, largely tourists, tended to purchase utilitarian items rather than jewelry or decorative wares. Thus, these artisans often sought support with designing utilitarian products. Using PET instead of plastic bags, I once again set out to design modern, utilitarian souvenirs that could bear vernacular design elements. I was intent on creating high quality products that required low skill levels to produce and could be sold in artisan markets in the Global South. Although the fabrication processes I chose were indeed simple, I struggled with the material.

Using permanent markers, I augmented scraps of PET bottles with pattern and colour before subjecting them to heat to cure the designs and alter their shape. Because the blow-molding manufacturing process used to create PET bottles and packaging (Marcus 1973) leaves the plastic is in a stretched state, heat activates the material's memory causing it to shrink to the substance's pre-blown dimensions. Thus, once shrunken, surface designs appear intricate and precise on the thickened plastic. I experimented with a wide range of plastic bottles and packaging, learning their respective shrinkage rates and thicknesses to assess their application to various products. The shrinkage ranged from 20–60 percent.[28] For warming sources, I experimented with an electric toaster oven and, in order to simulate low-tech situations, I also used candles. These techniques afforded different opportunities to shape the plastic by targeting heat to specific locations or to apply all-over heat to get uniform shrinkage. I purposely sought bottles and packaging containing brands (i.e. Coca-Cola, Nestlé) that would likely be found as waste in the Global South.

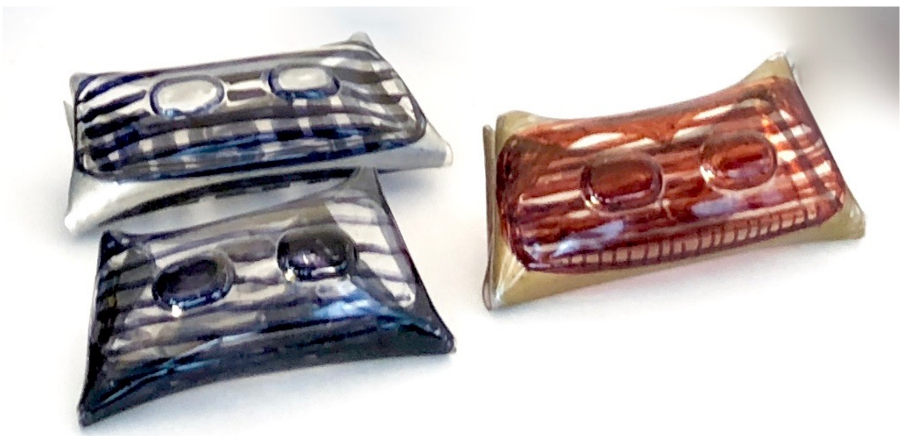


*Figure 14 Earbud holders, PET, Sherer, 2016*
*Figure 15 Sample Designs PET, Sherer, 2016*

I grappled with the material, searching for product designs that satisfied all my requirements. I found that the material lent itself very well to decorative household objects and could be used as a stained-glass substitute in many applications. However, the size of the material was limited to the packaging from which it was harvested. This issue, coupled with the shapes afforded by the molded bottles and packaging, proved limiting and not well suited to the types of products I explored. Some of the moderately successful, reproducible products I constructed include lidded containers and earbud and cell phone holders. As noted, since many artisan markets are flooded with a wide range of precious metal and fashion jewelry, I initially avoided this area entirely. However, despite my best efforts, the decorated materials' gemlike qualities inevitably guided me to create ornaments after all. Eventually, my studio-led research reminded me that instead of forcing the material to bend to my will, as a designer, I needed to bend to the will of the material. I had initially forgotten to follow the discoveries I was making about the material's capacities and to design objects accordingly; however, I ultimately recognized the need to alter my original design brief to include wearables.

I tried to model my own behaviour by being conscious of technological and resource limitations affecting makers in the Global South. I restricted myself to making jewelry that required low skill levels and simple tools to assemble and avoided purchasing commercial materials in lieu of using discarded materials. I incorporated found objects, again, likely to be easily locatable in the Global South, such as beach glass, reclaimed wire and e-waste as well as simple ribbon or scraps of fabric. I was then able to exploit the glazed appearance of the material that is transparent and glossy, but unlike glass, is neither fragile nor heavy. I found that the material was especially well suited to non-traditional forms of wearable sculpture and jewelry providing seemingly endless colour and shape combinations. I surmised that these objects satisfied several of the requirements in my original souvenir design brief; the wares were fabricated from waste using low skill and simple tools, were unique and distinguishable in artisan markets but could be devised using vernacular design.

*Figure 16 Blue Ring PET, Reclaimed Wire, Sherer, 2016*
*Figure 17 Red Ring PET, Reclaimed Wire, Sherer, 2016*

As I reflected on my studio research I was clear about the manner in which Up-cyclers benefit financially from using free or low-cost waste as raw material and the social benefit of creating closed loop communities with non-monetary and in-kind benefits. As I proceeded through my studio research however, I became doubtful regarding ecological impacts Up-cycling might provide. In my own experience of refashioning cast off materials, I used so few of the plastic bags and bottles I had collected, echoing Maycroft's findings, that the environmental impact of using waste will be relatively minimal at the scale that makers will produce these objects in their mostly home-based, cottage industry (2000, 154). Scholars agree on this issue, suggesting that, the broader ecological value of Up-cycling comes from the environmental awareness that is generated by artisanal wares that utilize waste as raw material (Feeley et al. 2014, 9). Using their Up-cycled products, makers intentionally or unintentionally disseminate their ecological message regarding use and disposal of materials (Milgram 2010, 81). By using an identifying hangtag on the water bottle holder which informs the consumer of the origins of the component materials, I witnessed an increased consumer interest echoing Milgram's conclusions that marketing materials can link an object not just to an exotic maker or locale but also to the human suffering caused by aspects of an environmental crisis (2010, 81). Apparel researchers and designers Han et al. similarly suggest that marketing materials can foster recognition of the true impacts of fast fashion and other similarly short life-cycled mass-produced merchandise (2015, 136). This awareness might influence consumer behaviour since attaching a face to environmental destruction fosters connections that can spur action in ways that facts and figures cannot (Sung et al. 2015, 354).

*Figure 18 PET Jewellery Samples, Sherer 2016*

After experimenting with Up-cycling these post-consumer waste materials, I understood that as raw materials PET bottles and polyethylene plastic bags had wide craft applications but offered only limited value with regards to waste diversion. Based on the proportion of usable plastics vs. offcuts and components that I returned to the recycle bin, it was evident that this Up-cycling process is truly only a stop-gap measure towards genuinely sustainable consumption practices. These materials, defined as "monstrous hybrids" (McDonough and Braungart 2002, 115-117) combine biological and technical materials that could never be truly Upcycled and are therefore only temporarily parked on their way to becoming landfill fodder. Hence, I investigated other manners of reusing waste that would have greater environmental impact by taking a long-term approach to managing material. However, although I was increasingly aware of challenges posed by Up-Cycling, I had not yet fully understood the benefits of creating products that, as Milgram points out, "respond to global market demands, but also foster channels of connectivity" (2010, 81). Thus, my studio research continued to evolve from my original quest to design objects that create community to the slow recognition that objects are already part of extant communities.

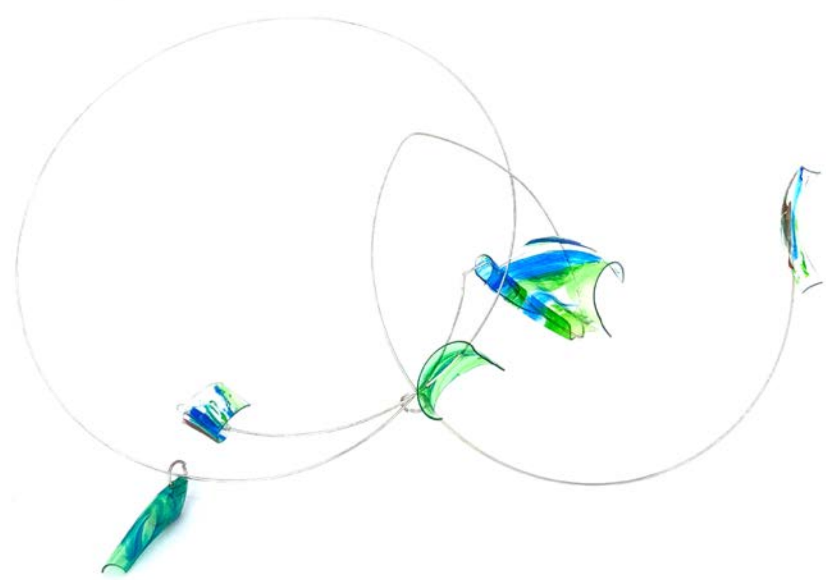

*Figure 19  Kinetic Necklace, PET, Spring Wire , Sherer 2016*
*Figure 20  Necklace, PET, Beach Glass, E-waste, Sherer, 2016*
*Figure 21  Blue Choker, PET, Ribbon Spring Wire, Sherer, 2016*

*Figure 22 Blue Spiral Ring, PET, Reclaimed Wire, Sherer 2016*
*Figure 23 Ring 2, PET, Beach Glass, Reclaimed Wire, Sherer, 2016*
*Figure 24 Broach, PET, Dressmaker Pin, Sherer 2016*

## Pineapple Paper

Still inspired by the notion of reusing waste, I began to investigate commonly discarded by-products that could be used as raw material. Once again, drawing on my work in Honduras, I recalled the heaps of agricultural waste rotting in fields or alongside roads. I have witnessed the slow smoldering of this agricultural waste being used as a method of repelling mosquitos and that the resultant ash is sometimes used to re-fertilize the land from whence the agricultural product was harvested. Yet, I wondered about other applications for this abundant by-product. I recalled that handmade paper is often made using pulp sources other than virgin wood as established by environmentalist Ed Ayers (1993, 2) and that commercial papermaking is an enormous global industry. Industrial chemists Adhikari and Bhattacharyya assert that "The global demand of paper and paperboard is about 402 million tons per annum and is still increasing" (2015, 2) and fellow chemists Aremu et al. add, "Wood contributes to about 90% of the conventional raw material used for pulp and paper production in the world" (2015, 1180).

*Figure 25 Handmade Paper, Urban Organic Waste, Sherer, 2016*


*Figure 26  Papermaking Experiments, Urban Organic Waste, Sherer 2016*

As I researched the relationship between agricultural waste and pulp and paper products, I set out to simulate very basic handmade paper production facilities in my Toronto home and studio. To simulate agricultural fibre available in pineapple growing regions, I collected discarded pineapple crowns from my local green grocer. My goal was to produce usable paper products with minimal labour or energy input, so I experimented with several low-tech methods for breaking the leaves down into usable pulp. I boiled the chopped fresh or dried leaves with varying amounts of soda ash and left some to rot or sour for weeks at a time, as one might do in a hot clime. Next, I beat the resultant pulp immediately or froze it to continue the decomposition process. Some pulp I pounded by hand using traditional paddling methods, some was ground in a kitchen blender and other pulps were processed using an artisan grade paper beater. From each of these experiments I used the pulp to cast three-dimensional objects and pulled sheets of paper of varying quality. I easily projected a variety of uses for each grade of pulp, ranging from handmade card stock and lamp shades to low grade packaging or insulating materials.

*Figure 27 Papermaking Experiments - Post-Consumer Fabric, Sherer, 2016*

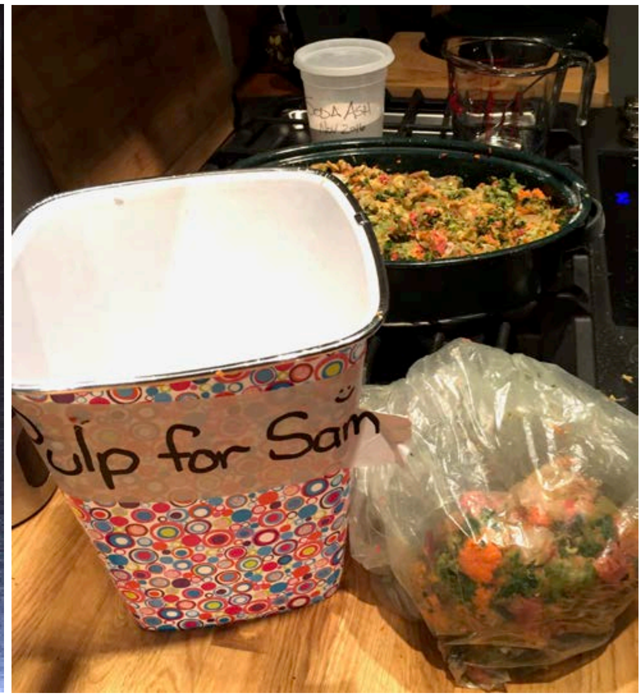


*Figure 28 Florist Shop Organic Waste, Sherer, 2016*
*Figure 29 Juice Bar Organic Waste, Sherer, 2016*

Recognizing that organic waste was not limited to agricultural areas, I became interested in sources of urban organic waste. I collected cuttings from a florist shop including unwanted stems, damaged flowers and trimmed leaves. This too was boiled and beat using a variety of methods, again making paper and cast products of varying quality. I then sought waste from commercial juice counters. This pulp proved to be ideal for papermaking as it was already partially masticated by the juice extractors. Because it is generated in proportionately large volumes, juice counters were pleased to hand over their pulp, considering it a nuisance by-product in urban centers where waste management can be costly. Since yields from this pulp were high it is reasonable to assume that this could be a valuable and reliable source of pulp should this industry form partnerships with pulp and paper producers at an artisanal or industrial scale.

During the process of fabricating handmade paper from unwanted by-products, I became concerned about the effluent generated by boiling the organics and the water consumed in rinsing and preparing the pulp. I used copious amounts of water, enriching it with nutrients and contaminating much of it with soda ash, which required neutralisation or other treatment before it could be safely returned to the water table. I learned that the, “Pulp and paper industry is considered as one of the major polluters generating large volumes of colored and toxic effluents containing around 240–250 chemicals while consuming 50–60 m$^3$ of water per ton of paper produced” (Adhikari and Bhattacharyya 2015, 2). I also discovered that, relative to its growth cycle and proportionate food yield, cultivating pineapple creates large carbon and water footprints (Moss 2011, 10). I became even more convinced of the need to valorise agro-waste in order to offset the year-round global demand for pineapple and other exotic produce.



*Figure 30 Artisan Paper Pulping, Urban Organic Waste, Sherer, 2016*
*Figure 31 Artisan Paper Pulling, Urban Organic Waste, Sherer 2016*

*Figure 32  Artisan Paper Experiment, Urban Organic Waste, Sherer 2016*

There is a great deal of existent research regarding alternative cellulose sources for the pulp and paper industry[29]; however upon surveying the literature, it appeared to me that these endeavors are mainly lodged within the current paradigm of manufacturing and they focus on simply substituting virgin wood with agro-waste without addressing concerns regarding the displacement of nutrients. I wondered about setting up industrial or artisan paper production facilities adjacent to an agricultural area. Where would the water come from? Could the effluent and waste water be used as a fertiliser? If the burnt agricultural waste ash had historically been used as fertiliser, what would be the impact of eliminating this practice? Could the impact be offset by returning the effluent to the fields instead of the pulp itself? How would the cessation of burning the waste, but then transporting the nutrient rich water, impact pineapple's carbon and water footprints? If burning ash no longer acted as an insect repellent what of mosquito borne diseases?

As I reflected on my small studio project of creating handmade paper from organic waste, my focus became more tangential, reminding me that few problems exist in isolation. By being conscious of the inter-relationships between people, place, flora and fauna, I was beginning to see the organic waste as a component of a larger network. While these questions regarding agro-waste continued to intrigue me, I decided to use the specific challenges, of pineapple cultivation and the pulp and paper industry as a case study to consider issues of global industrial manufacturing supply chains as a whole. In this vein, I asked myself, “What other uses could be found for the by-products of pineapple growth? What of the skins and cores discarded in the canning process? What of the heat generated by the canning machinery? What of the biological nutrients contained in the pineapple that are shipped out of the region? What of the people who grew, harvested or processed those pineapples? How were they (or could they be) related to those who ate them?” I had an inkling that these questions were somehow related to my original wishes regarding fostering community and my curiosity was peaked.

*Figure 33  Paper Casting, Urban Organic Waste, Sherer, 2016*

However, as I researched pineapple cultivation and the pulp and paper industry and became aware of staggering statistics regarding virgin wood, paper products and packaging, I understood that artisan usage of agro-waste to produce paper products would have limited environmental impact. Indeed, I learned that protecting tree canopies and global environmental health would require the pulp and paper industry to change its entire model rather than simply taking up the use of alternative pulp sources. An entirely new manufacturing supply chain and distribution paradigm would be required.

Now I knew I was circling in on my interests in community. I saw the web of interconnectedness and knew that solving one isolated problem could cause inadvertent effects in other areas. I no longer felt satisfied with designing solutions for a single element of the perceived whole. Soon I understood that the question of global environmental health was not one that could be addressed by industry specific "less bad" (McDonough and Braungart 2002, 45) manufacturing practices. I also noted that, while the potential unintended side-effects of altering manufacturing practices could do more damage than good to the whole, these inadvertent consequences could also be harnessed in order to improve adjacent challenges within a community. I recognized this line of questioning as "systems thinking" (Mang and Reed 2011, 3) and saw that Sustainable Design principles could not adequately address the problems associated with global manufacturing or environmental health. I noted that they are "wicked problems" – a category of problems that are systemic, malignant and indeterminate in nature and therefore can have no single solution (Rittel and Webber 1973, 161-166). This "discovery" led me to literature regarding CE and eventually to Regenerative Development, an entire field dedicated to systemic health (Mang and Reed 2011, 14). As my project shifted, I edged closer to my original quest; to design objects that could create community.


*Figure 34 Handmade Urban Organic Waste Paper, Sherer, 2016*
*Figure 35 Waste Paper Bowl, Urban Organic Waste, Sherer, 2016*

Though assigning value to Up-cycling is complex and ever-evolving, new light can be shed on this discourse when paralleled with the unprecedented development of the Maker Movement and the field of AM. For instance, while in 2000, Maycroft expressed concerns regarding the revalorization of waste, this article precedes the current DIY culture. The Maker Movement, coined roughly in 2005, was kindled by the proliferation of 3D printers, the abundance of post-consumer waste and the new form of sharing economy that sprouted out of the now ubiquitous access to the world wide web (Park 2015, 271). By 2013, Maycroft and co-author Bramston, embrace a more hopeful position regarding use of waste in the manufacturing cycle. Within the context of Up-cycling, they suggest that the new generation of "Unknown 'creatives' – those individuals who understand and can respond to an immediate problem" (2013, 132-133) – are solving everyday needs through experimentation and curiosity. Maycroft and Bramston respectfully acknowledge the ingenuity often displayed by citizens of impoverished circumstances in the United Kingdom and South America and suggest that an uptake of their vernacular approaches to design, be it thrift or "Old World" ingenuity, could lead design toward material stewardship and away from unmoderated consumption. They observe that, "the average occupant of a favela or owner of an allotment is probably not design educated but their approach to thinking is inspirational and worthy of exploration to appreciate emerging opportunities" (2013, 129). The authors optimistically conclude that global and locally minded members of the Maker Movement, coupled with the deftness of their manufacturing methods, exhibit the autonomy of thought and interdisciplinarity that may actually disrupt the standard take-make-waste model of global manufacturing (2013, 129). In the following section, I build on Maycroft and Bramston's research to argue that combining Up-cycling principles with AM techniques can provide even further hope for curbing global consumption by enabling Distributed Manufacturing.

## Ceramic 3D Printer

While experimenting with Up-cycling, I simultaneously began to explore the realm of computer aided drawing (CAD) and manufacturing. After a brief foray into designing objects using CAD software programs, I developed an interest in the hardware of Additive Manufacturing, 3D printers themselves. Here was an entirely new world of production, growing at an exponential pace fueled by global rhyzomatic learning. Outcroppings of practice-led research continue to rapidly generate new knowledge. Moreover, many makers freely share their discoveries and inventions in open-source technology warehouses and DIT forums (Sung et al. 2014, 241). I identified commonalities between Up-cycling and AM. In both forms of fabrication, the makers tended to be ingenious and resourceful in their use of material, freely sharing techniques in their respective makerspaces and online platforms, even crossing into each other's forums as necessary. As we have seen, research also indicates that Up-cyclers and Digital Makers often share values regarding consumer culture and attitudes regarding misuse of materials. Thus, I became interested in the rapidly growing field of AM regarding its impact on craftspeople and designers and ultimately its potential to disrupt global industrial manufacturing.

*Figure 36 3D Printed Ceramic Samples, Cone 6 Porcelain, Sherer, 2017*

Due to the ubiquitousness of RepRap 3D printers as discussed, Jephias Gwamuri and fellow engineering researchers suggest that a new digital universe of open-source files for printing objects (2016, 1) and the cooperative nature of the DIT Movement (2014, 240), manufacturing practices in the Global North can become a democratized activity that no longer solely resides in the hands of global corporations. Local, bespoke manufacturing could resemble pre-globalization times, or the Custodial Consumer era, (Crocker 2015, 83) when decentralized production and trade were the norm and importing goods from afar was considered a luxury. I was reminded of developing economies in the 1990s as they leapfrogged technology by adopting cellular phone networks without ever having implemented a landline infrastructure. From this observation, I can infer that by eschewing expansion of conventional manufacturing factories and progressing directly to AM, some developing economies could conceivably skip an entire level of industrialization, thereby moving directly into Schwab's Fourth Industrial Revolution (2016, 77). Although outside the scope of this paper, Schwab argues that the variety of repercussions of this possibility are staggering (2015, 1-9).[30]

After learning about RepRap for polymers and its potential to facilitate DM, I was inspired to explore AM's potential to stimulate Regenerative Development. I was curious about other types of printing devices that might be constructed from open-source files and the possibility of printing materials other than plastics.[31] Were there 3D printers other than RepRap that might be appropriate, open-source technology in the Global South?

Were the open-source files self-explanatory or readable by novices? Would there be sufficient access to parts and technical support for ongoing maintenance? Could I use practice-led research to explore the reproducibility of a 3D printer in the Global South? Because I was a "digital immigrant"[32] and had no knowledge of electronics nor any actual studio experience of AM, it made sense to seek answers using myself as a test subject. Thus, I went in search of a 3D printer suitable for this case study.

With my background in studio ceramics, I naturally gravitated toward paste extrusion technology, a variant of Fused Deposition Modelling (FDM)[33] and how it may be applied to ceramics (Zocca, et al. 2015, 1984-1997). After locating an open-source file for a Delta style 3D printer (Czibesz 2017) adapted for use with ceramic materials, I set out to build one of my own. In fact, I intended to build an entire 3D printing system which in addition to the printer, included an open-source pneumatic extruder, which feeds clay paste to the print head via polyurethane tubing and an optional print head auger to regulate the flow of paste through the extrusion nozzle. In my naiveté, I had no idea that the project was going to be so arduous, frustrating and surprising, but I chronicled my experience in reflexive notes and documented the assembly with stop-motion video.

While I focused the research for this paper on applications for ceramic materials, this 3D printer could be used to extrude any kind of paste formula, from chocolate to cement, affording it much broader applications than simply increasing a potter's repertoire of tools. As such, I believed it to be a suitable choice for my case study. With my open-source files downloaded, I joined DIT networks in online forums and settled on building Bryan Czibesz's[34] scaled version (Czibesz 2017) of Jonathan Keep's [35] Delta 3D printer (Keep 2014) that included an Secure Digital card reader, Arduino computer board[36], a pneumatic extruder and a print head auger.

*Figure 37 Ceramic 3D Printing System, Sherer, 2017. Photo: Kristy Boyce*

And then, I actually built a ceramic 3D printer. Simply put, this printer layers horizontal rows of soft clay paste to translate a CAD computer model into a piece of greenware (unfired ceramics.) A secure digital card translates the file of the CAD model to a small computer board that drives the four stepper motors and 3 end-stops. One of the motors controls the speed of the auger and the delivery of paste. The remaining three motors, according to information extracted from the original CAD drawing, control the 3 robotic arms, to position the extrusion print head relative to the print bed, on a three-point coordinate system (or in 3 dimensions, up & down, side to side and back to front). In practice, the layers of clay resemble neatly stacked horizontal coils or bands that can be smoothed out post printing, in accordance with the maker's wishes. However, there is a quality to the regularity of the layers that reads as "mechanical" and imperfections in the extrusion process create subtle waves within the line pattern that are unique to 3D printed paste. These waves have become a signature of 3D printed paste, more often exploited than smoothed away.

The process of using open-source files to create my 3D printer proved to be more difficult and costly than the literature suggests. The Thingiverse files include stereolithographic (STL) files for the plastic printable components and 3DM files for the computer numerically controlled (CNC) wood components, totaling perhaps one-third of the parts. Also provided are firmware files to configure the Arduino computer board and a Bill of Materials (BOM) or a shopping list for standard hardware and electronic elements. I purchased components locally when possible but many parts had to be imported directly from China, and as such, they were subject to long shipping times. Sadly, despite some electronic parts arriving broken, with free shipping, ordering items from China still proved significantly cheaper and less time consuming than local shopping – more than an ironic twist given that this research focuses on Distributed Manufacturing. I was thus mindful of the potential repercussions to a project in the Global South. Ultimately, the total cost of the combined components was approximately $900 CAD but with more experience, I have identified areas where costs could be significantly reduced for future builds.


*Figure 38 Components Ceramic 3D Printer, Sherer, 2017*

After collecting the necessary pieces, I began to assemble the four components of the printing system. I floundered initially, despite working in ideal conditions in Toronto, Canada. I had never actually seen any of the components and thus was building somewhat blindly. Because Thingiverse files are often works-in-progress (WIP), as a novice, I found them difficult to follow. Lacking significant familiarity with the final product or fluency with the open-source networks, references to parent or offspring designs were confusing and as such, images or video "instructions" were insufficient to replace notated directions for assembly. To be clear, files are labelled WIP, implying that parts lists will change, multiple files for a single component might be found and instructions might not be updated with each iteration. I now understand these challenges to be likely when using open-source 3D models or software. Moreover, this particular system contains four components, requiring an extremely diverse skillset to assemble. Apparently, consultation from online networks is expected as is sharing of findings. However, as a digital immigrant, I likened the experience to gathering a box full of hardware, wood, plastic and metal parts with the following instructions, "Contains one extruder, one ceramic 3D printer, one auger, one computer and an unknown quantity of surplus parts. Assembly required. Note, components may be missing or require alteration. Model may not be a reasonable facsimile of associated images."

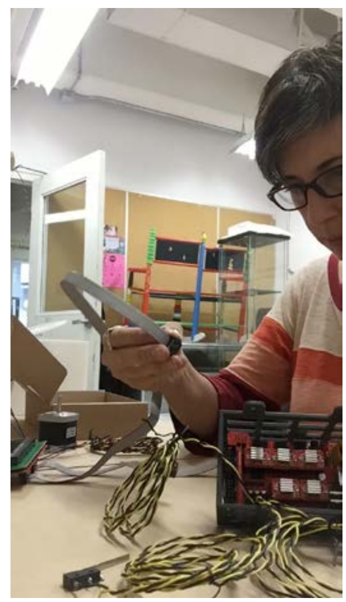

*Figure 39 Components Pneumatic Extruder, Sherer, 2017*
*Figure 40 Assembling the Arduino, Sherer, 2017*

Using online platforms proved equally challenging; however, while surveying the content of Additive Manufacturing DIT forums, I recognized the same spirit of comradery, generosity and cooperation that Sung referred to as "social benefits" of Up-cycling (2105, 31). Ultimately, I mined a great deal of support from these forums despite their Q&A

format that inevitably led to meandering threads of technical discussion, which disperse, entwine and bury valuable information. Nevertheless, I could see the appeal of these online forums as they enabled me to troubleshoot obstacles or learn from other's experience at any time of the day or night from the comfort of my own studio, regardless of my geographical location. As a result, I was ultimately able to build the four-part printing system. Using a combination of information mined from the Thingiverse files, software and hardware websites and various online forums, it was technically possible to identify, download and install the firmware and slicing software required to run the printer's small computer board. However, given that I had no prior knowledge of electronics or computer programming, this aspect proved difficult and too time consuming for the scope of the project. I sought expert IT support for this part of the assembly[37] and noted that other digital immigrants would likely require similar support.

*Figure 41 Assembling Ceramic 3D Printer System, Sherer, 2017*


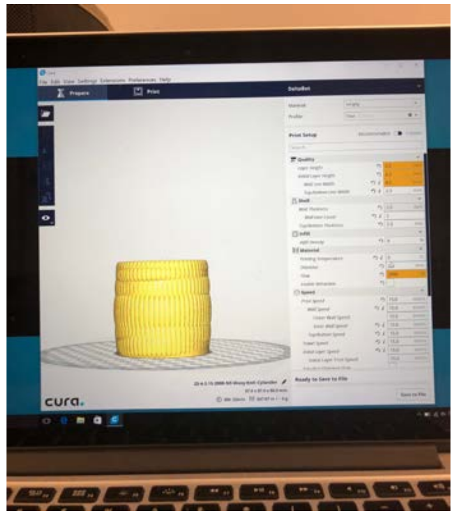


*Figure 42 Arduino and SD Card Reader, Sherer, 2017*
*Figure 43 Cura Settings, Sherer, 2017*

I believed that the final steps would be locating claybodies suitable for printing, mixing them to workable rheology and loading the pneumatic extruder. This too proved complicated, as in order to get the clay to extrude through the nozzle, the viscosity of clay had to be matched with shrinkage, nozzle gauge and air pressure. In addition, I found that a mismatch in auger speed, print speed, material diameter, flow, layer height and other settings in Cura, the slicing software, could upset the balance and botch the prints.[38] Finally, I discovered one last variable, namely the conversion from the CAD drawing file to an intermediate STL file format required by Cura. These files needed to be drastically simplified in order for the small Arduino computer board to be able to process them quickly enough to match the flow of clay – a simple solution, had I only been warned. Eventually, plumbing the depths of DIT networks, I did find this information buried deep within a conversational thread. This was an example the many demoralizing delays and needlessly failed prints due to a lack of coherent assembly and usage instructions. For the sake of my research, I also wondered how the experience might have differed if English hadn't been my first language. As it was, through perseverance, ingenuity and a great deal of trial and error, I did eventually deploy the printer to consistently produce satisfying and accurate representations of models I drew in Rhino.

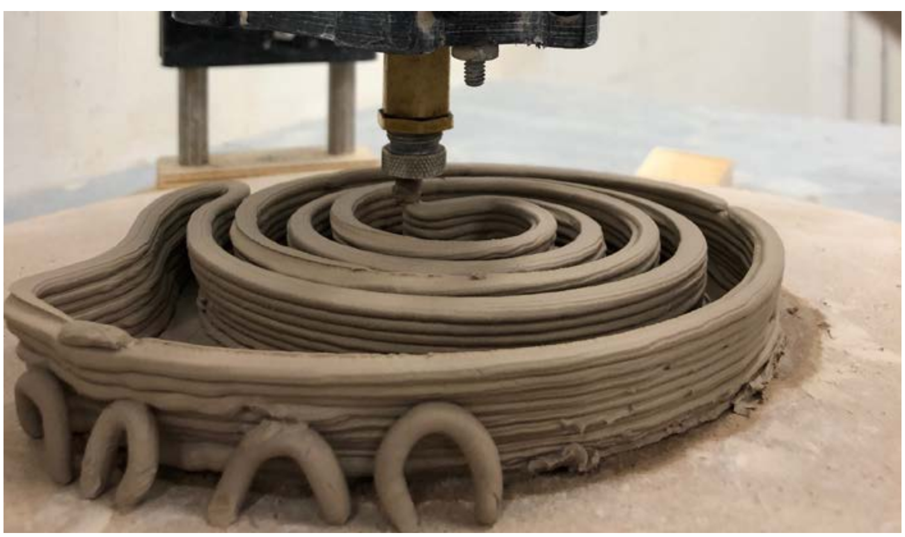

*Figure 44 Loading the Extruder, Sherer, 2018*
*Figure 45 Glitch, Unattended 3D Print, Cone 6 Porcelain, Sherer, 2018*
*Figure 46 Improvised Supports, Cone 6 Porcelain, Sherer, 2018*

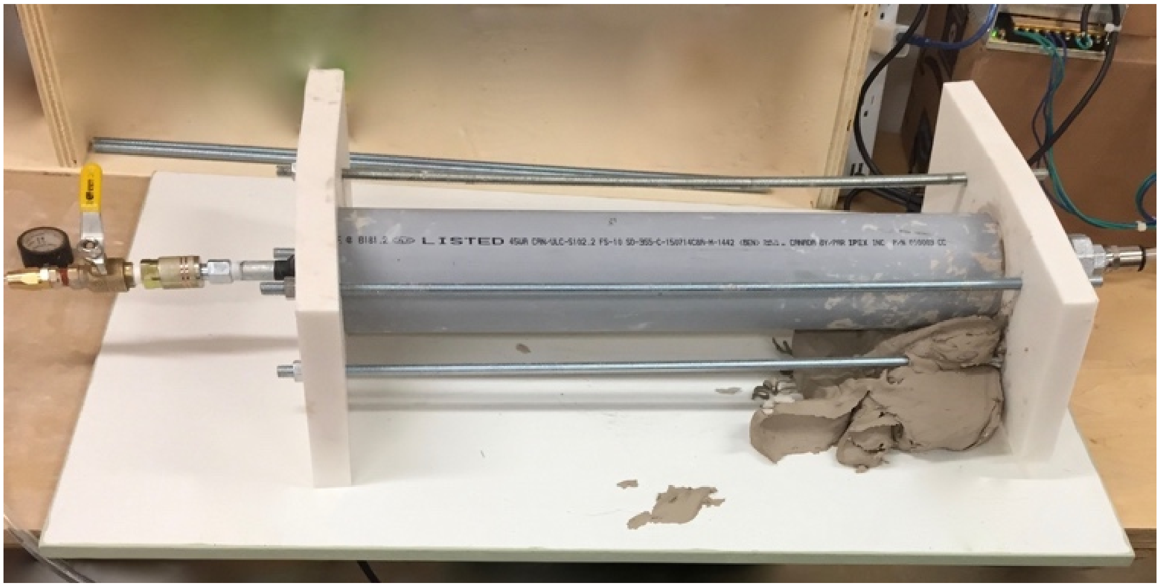


*Figure 47  Extruder Blowout, Sherer, 2017*

The challenges I experienced building this open-source technology are among those identified by scholars concerned with the use of open-source appropriate technology in the Global South outlined earlier in this paper (Despeisse, et al. 2017, Feeley et al. 2014). As I continued to use the printer, I identified areas of the structure that were not robust enough for my needs. As components broke, I attempted to repair them in the way that Bramston and Maycroft’s favela dwellers (2013, 7) might have done. I used salvaged telephone wire, shims and other ad hoc solutions to patch up the printer and get it working again. I also identified areas of the components I could adjust to better suit my needs. The result of experiencing these challenges was the knowledge that while an eager potter may struggle to build this four-part printing system, once built, the assembly and ongoing maintenance would likely become as intuitive as maintaining existing equipment.

Contrary to the optimistic research regarding 3D printing and DM, scholars agree that not all barriers to OSAT have been adequately addressed (Rehnberg and Ponte 2017, 19). Srai et al. suggest that AM faces potentially significant barriers to uptake in the Global South and thus disruptions to global manufacturing chains are, by no means, a fait accompli. As Srai et al. note:

> There remain significant adoption challenges limiting such convergence and the distribution of manufacturing through 3D printing. Participants of the 3DP-RDM [3D printing for redistributed manufacturing] network have identified these challenges to include 3D modelling; material supply chain issues; standards (including file formats), compatibility, regulation and certification; the absence of software and conceptual infrastructure; the ability of organisations to create and capture value; ownership issues; and business model uncertainty. (2016, 6922)

Using my case study of building the Delta 3D printer in the Global North, I have similarly identified potential challenges that might be addressed with research and education. Just as I needed IT support, some makers in the Global South will similarly require technical support and I remain uncertain if this is as readily available across all regions. As noted, I found enough information available in English for my own project but I did not research DIT forums in other languages and cannot speak to the quantity or quality of available information. I am also aware that the whole concept of using AM technology in the Global South presumes that makers have access to electricity, internet connections, computers and software in addition to the expertise required to use CAD modelling programs. As per plans for Keep's original Delta 3D printer (2014), makers without access to digital manufacturing tools could build the components that I printed or milled using local materials and analog tools. Likewise, I am interested in exploring emerging iterations of the auger/print head combination that rely on stepper motors to force paste through the nozzle thereby eliminating the need for compressed air (Keep 2017). Although CAD programs I encountered were mainly proprietary and costly, increasingly CAD software is being developed for open-source use (Nilsiam and Pearce 2017, 3). In the interim, open-source warehouses host a rapidly growing catalogue of files, such that even without access to CAD programs, makers could conceivably download other's objects or designs for their own use (Nilsiam and Pearce 2017, 2).

*Figure 48 3D Printed Ceramics Sample Bisque, Cone 6 Porcelain, Sherer, 2018*

Despite potential barriers, the Delta style printer is easily scalable and lends itself well to printing all sizes of discrete objects.[39] In addition, these printers are extremely versatile, requiring only software adjustment for use with a growing list of segregated bio or technical materials including, food pastes, cement, metal and wood suspensions. Traditional FDM printers often rely on proprietary filament requiring controlled humidity environments for storage and precise nozzle temperatures for printing. Some of these polymer filaments, which are designed to look like wood or other natural materials, including ceramics, are in fact "monstrous hybrids" of bio nutrients with polymers, which cannot be Upcycled and are therefore an unsustainable use of resources. Because paste 3D printers can be used to produce a wide variety of useful objects, they could certainly lead to the democratization of manufacturing (Pearce, et al. 2010, 19). As we have seen, by decentralizing production and supply chains, Distributed Manufacturing can generate a wide range of social and environmental benefits, leading me to conclude that the Delta 3D paste printer could make a significant contribution to programs of Regenerative Development. I began to wonder if I had located an object that could create community?

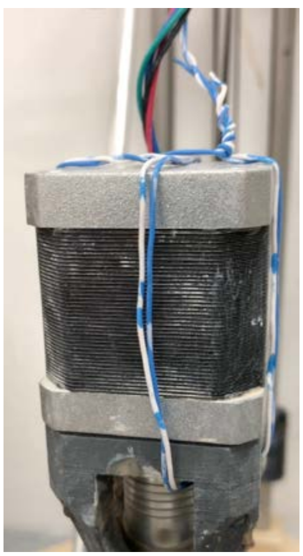

*Figure 49 Jerry Rigged Auger, Stripped Screw holes, Sherer, 2017*
*Figure 50 Adjusting the Variables to Minimize Auger Ooze, Sherer 2017*
*Figure 51 Broken 3D Printed Effector Head, Sherer 2017*

I reflected on the experience of building this 3D printer and related it to my recollections of building point-of-use ceramic water filter factories in parts of Asia and the Americas. As per Bramston and Maycroft (2013), I too encountered makers who demonstrated resourcefulness, ingenuity and frugality when building or repairing machinery. As such, I believe that with minimal improvements to open-source files and/or the availability of more complete instruction manuals, artisans and makers in the Global South would likely be able to assemble a variety of 3D printers and other forms of AM. While I acknowledge that I did feel discouraged at times, with support from geographically dispersed, unfamiliar resources located on the fringes of my community, I was eventually able to unite the components into a working 3D printing system. I found the outcome gratifying and empowering and took pride in revealing our shared successes to my supporters. I am humbly aware that I did not do it alone; it took a village to build this printer.

I now recognize a tangible, potential pathway to embolden an entirely new, diverse generation of makers in the Global South and the possibility of fostering local and intercontinental alliances where none had been before. Thus, the Delta Ceramic 3D printer paired with Czibesz's extruder and auger combination, ultimately proved to be a challenging example of a tool of Distributed Manufacturing and OSAT in the Global South. However, this project could only be viable, provided the maker has access to a computer and internet connection and to imported components. The entire process is made more realistic (and beneficial) if the maker also has access to individuals with complimentary skills. In short, it takes a community to build the Delta 3D printer, or maybe it creates one.

*Figure 52  Ceramic 3D Printed Vessels with 2 variants of thing:268924, Sherer, 2018*

## Conclusions

My project has shown that Additive Manufacturing has potential to alter the global economic landscape and resituate individuals within their local ecological and social systems. Consistent with principles of Regenerative Development, AM has the potential to redistribute global manufacturing to localized production focused on economies of scope. When coupled with Up-cycling techniques, plastic can be harvested from landfills and polymer 3D printer filament can become a locally manufactured product. When filament or paste formulations include Upcycling principles so that biological and technical materials are segregated, AM has documented potential to create a nutrient loop within a Circular Economy. Localizing supply chains could reconnect makers and consumers fostering ecological awareness of material composition and consumption. It follows that by increasing a sense of local, environmental responsibility using a circular flow of commodities, water and carbon footprints could subsequently be reduced. However what thrusts Distributed Manufacturing beyond environmental and financial benefits are the associated opportunities for social impact of folding informal economies into the mainstream, reintegrating low-income fringe dwellers and creating diverse DIT cooperatives that strengthen community bonds. These interdisciplinary concerns move beyond Sustainable Design principles and align Distributed Manufacturing outcomes with the philosophical ideals of Regenerative Development.

Yet, as we have seen, democratizing manufacturing does not guarantee the displacement of global value chains or the paradigm of unsustainable consumption.

Spontaneous uptake of new technology does not ensure stewardship of materials or that eco-effective processes will become the norm. Intervention and education will be required to ensure that global consumerism and mass production systems are indeed disrupted. We humans must first accept that objects, flora and fauna, even those as yet unborn, are each part of our global community. Only then might we diverge from deceptive Sustainable Design practices to allow holistic, Regenerative Development to become our collective goal.

## Reflections

Although I diverged from my original goal, this project produced many unintended benefits. Amongst the unexpected lessons was my introduction to a new universe of sharing economies and open-source networks as well as the diversity of the individual makers and DIT communities. In the end, I did not invent any Up-cycling methods or devise any part of the Additive Manufacturing components or processes used in this research. Ultimately, I did not design an object that creates community. I do however, strongly believe that this has been a fruitful research project. I recognize that, like many design practices, my focus may have been too narrow to generate an impactful solution. The problem of “building community” is too “wicked” for such a one-dimensional approach. I needed to step backwards in the design process in order to re-examine my primary questions. Only then could I recognize that solving one problem inevitably led to creating or identifying another.

Yet, I fought the community that the 3D printer was endeavouring to create. Apparently, Individualism is a hard ideology to shed given how determined I was to build the printer myself. I permitted myself to request assistance only when I was completely stumped. Yet, at the university alone I had access to a panel of professors and studio technicians who generously provided resources; a team of allies cheering me on. Because of my reliance on open-source technology and several DIT forums, unbeknownst to their members, I also had support from designers, potters, makers and hackers on five continents. A group of individuals had assembled who respected my agenda, collaborated with me, contributed resources and information towards a common objective, encouraged me when I was disheartened and celebrated when I (but really, we) achieved our goals. While I truly valued these helpers throughout the process, it was only after I completed the build that I recognized them as a community that had come together as a result of this project. Although initially I wanted to have the achievement all to myself, I happily surrendered when I recognized that I was fighting the very community I had been attempting to create. True, I had not designed an object that creates community but somehow, one had formed anyway.

As a result of this project, my image of “community” has shifted considerably. I see now that we can recognize a community, perhaps we can even join one, but we can never see the beginning or end of one because it does not exist. A tendril or spore is always just out of sight. I have come to challenge the very premise of “creating community.” At best perhaps we can seed communities using cuttings from existing ones. I believe this research has shown that either sowing AM technology in the Global North or transplanting it to the Global South has the potential to do just that. As an act of Regenerative Development, open-source appropriate technology in the form of Additive Manufacturing can act as a spore from whence offshoots organically grow. However, in order for AM to seed community, we must target its growth such that the technology can flourish where it is needed and cultivate Distributed Manufacturing. Finally, we must be mindful that transplanting Additive Manufacturing is only a case study for a much larger need to broaden education regarding stewardship of materials and in the process, safeguard the wellbeing of our global community.

## Next Steps

In order for AM to disrupt global value chains, we have seen that targeted educational campaigns are required. While I continue to make things that make things, I intend to support others to do so as well. I believe that there is a great deal of reciprocal learning that can take place between makers in the Global North and South. To be sure, I have equally benefitted from any technical consultancy that I have ever provided. At a minimum, I mimic the resourcefulness, ingenuity and thrift of my Global South colleagues within my own practice. I have also gained the confidence to be inventive, recognizing that the design practice of "making do" is often in reality "making better." I enjoy translating these sensibilities to my Global North colleagues and hope to build on this work by creating a new type of educational FabLab to perpetuate the democratization of manufacturing.

I aim to expand the current MIT model of the FabLab,[40] by including craft-based digital and analogue tools in the makerspace. This practice-led research facility will continue the work of disseminating knowledge pertaining to AM's socio/economic potential. In addition, this space may become a hub of software and hardware development in order to increase the accessibility of low-cost, open-source Additive Manufacturing technology to individual makers on any continent. My methods will continue to be informed by my accumulated field experience and by facilitating maker exchanges I hope that I can contribute to an ongoing dialogue between makers in the Global North and South.

*Figure 53 It's Alive! Sherer, 2017*

## Endnotes

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1 For one of many substantive histories of CE the author recommends reading, MacArthur, 2012.

2 Informal Economy (Smart and Smart, 2017), Solidarity Economy (Miller 2009), Shadow Economy (De Soto 2013), Extralegal Economy (Smart and Zerilli, 2014).

3 For a brief summary of the current Global North economic model as well as of the Solidarity Economy, I refer the reader to Ethan Miller's extensive writing on Solidarity economies (2009, 25-40).

4 "A performance economy is a variant of Circular Economy and "goes a step further by selling goods (or molecules) as services through rent, lease and share business models (4,5). The manufacturer retains ownership of the product and its embodied resources and thus carries the responsibility for the costs of risks and waste" (Stahel 2016, 3).

5 For an optimistic description of the Upcycle as DfD see Design for Reuse (Richardson 2011,3)

6 This author notes the concepts of Circular Economy are conflated with several other terms or design theories and often share some or all of the basic principles and history. Though not an exhaustive list, see appendix 1 for examples.

7 For a detailed history of sustainable design see (Findeli 2008) or (Mang and Reed 2012) For a detailed critique of Sustainable Design, see Margolin (1998, 84) or Madge (1997, 53).

8 Referring to a publication of proceedings from a 1976 conference, (Bicknell and McQuiston 2014)

9 Recall that Up-cycling is a process that can slow the progress of filling dumpsites with obsolete products by reusing post-consumer waste to make new objects. Upcycling, a term related to Circular economy is the reuse of an object as is, without recycling or remanufacturing, cascading it down toward its eventual reclamation as a bio or technical nutrient.

10 In addition, Norris' concerns regarding recycling, another pitfall of global recycling programs is that once nutrients are removed from the community, the truly Regenerative process breaks down.

11 Also see Feeley et al for discourse on concerns of perpetuating global manufacturing power structures with fair trade plastic.

12 For a detailed definition of Up-cycling and related terminology see "A review on Upcycling" (K. Sung 2105)

13 Failing this solution, as Up-cycling applications have been exhausted and dump yards overflow, a hopeful final step for these products could be to generate energy through clean burning, waste-to-energy incinerators. However, Wilquest et al (2017) warn that material contaminants persist, making recovery of nutrients from fly ash costly and complete elimination of waste impossible. (2017, 484)

14 For a comprehensive description of the global reality of waste pickers see Feeley et al. (Feeley et al. 2014)

15 For a thorough explanation of the evolution AM in commerce see (Rayna and Striukova 2016, 215).

16 For a thorough discussion of the scope and challenges of Distributed Manufacturing see, Srai et al. 2016

17 While significant, commerce aspects of distributed manufacturing fall outside of the scope of this paper.

18 "Fab Lab is the educational outreach component of MIT's Center for Bits and Atoms (CBA), an extension of its research into digital fabrication and computation. A Fab Lab is a technical prototyping platform for innovation and invention, providing stimulus for local entrepreneurship" (What is a Fab Lab? 2016).

19 “The term originated in the context of software development… …Open source projects, products, or initiatives embrace and celebrate principles of open exchange, collaborative participation, rapid prototyping, transparency, meritocracy, and community-oriented development” (Red Hat, Inc. 2010).

20 “The word RepRap is short for Replicating Rapid-prototyper […] It is the practical self-copying 3D printer […] a self-replicating machine […] Following the principles of the Free Software Movement we are distributing the RepRap machine at no cost to everyone under an open source license” (Bowyer 2005).

21 A RecycleBot is a waste plastic extruder that creates 3-D printer filament from waste plastic and natural polymers” (Pearce, et al. 2017).

22 For a short literature review of Additive Manufacturing as circular product design, see (Saurewein, Bakker and Balkenende 2017).

23 Like Maycroft, Despeisse et al. note concerns with distributed recycling, discussed further in this paper.

24 See appendix 2 for a short list of companies and products using Up-cycling and/or Additive Manufacturing in a progressive manner.

25 In general, waste pickers are a marginalized segment of the urban population within the developing world that earn a living sifting through trash in order to sell recyclables. Waste pickers can do bulk recyclable materials, but often target higher-value products than waste plastic containers. (Feeley et al. 2014, 5).

26 Political economists Rehnberg and Ponte emphasise the uncertain trajectory of adoption of 3D printing in the Global South and outline two opposing possible scenarios. They hypothesize, “the complementary scenario,” where the existing structures and power relations remain in contrast to “the substitution scenario” whereby 3D printing and AM technology facilitate significant transformation in manufacturing global value chains26 (2017, 18).

27 See appendix 2 for a list of social enterprises using Up-Cycling.

28 Records of shrinkage rates defined by brand may not be applicable to similar product packaging across all geographic locations necessitating onsite testing for relevant data.

29 I can give a list of resources if this is warranted

30 Schwab’s Fourth Industrial Revolution (2016) gives a comprehensive theoretical view of potential outcomes. “We are witnessing profound shifts across all industries, marked by the emergence of new business models, the disruption of incumbents and the reshaping of production, consumption, transportation and delivery systems. On the societal front, a paradigm shift is underway in how we work and communicate, as well as how we express, inform and entertain ourselves. Equally, governments and institutions are being reshaped, as are systems of education, healthcare and transportation, among many others. New ways of using technology to change behavior and our systems of production and consumption also offer the potential for supporting the regeneration and preservation of natural environments, rather than creating hidden costs in the form of externalities.” (Schwab 2016, 2)

31 “The Fab@home printer, which was designed at Cornell University by Hod Lipson and Evan Malone, (…) much like the RepRap, uses a three axis system driven by stepper motors and uses extruded layers of working material to build up the 3-D shape (Malone & Lipson, 2007). The Fab@home, however, uses a syringe based extruder that currently allows for many more materials than the RepRap (Pearce, et al. 2010, 19) For a thorough history of the evolution of desktop 3D printers see all3dp.com/know-your-fdm-3d-printers-cartesian-delta-polar-and-scara/

32 A self-explanatory name I coined in contrast to the term “digital native,” which refers to persons born after the technical revolution to whom digital technology is considered intuitive.

33 For an excellent description of the various AM technologies see www.3dhubs.com/knowledge-base/Additive-manufacturing-technologies-overview#material-extrusion.

34 Bryan Czibesz (Zibes) is an award winning ceramic artist and is currently Assistant Professor of Art in Ceramics at SUNY New Paltz. I used Czibesz's open-source files for the pneumatic extruder and auger. Delta 3D Printer for Ceramics by Zibes Published on August 21, 2015 thingiverse.com/thing:977275.

35 Jonathan Keep is an award-winning studio ceramist who lives and works in Suffolk, England. His website has an instructional video and assembly instructions that provided helpful guidance for assembling my 3D printer, which was an adaptation of his design. I recognise that Keep's printer is likely more OSAT since his original mandate was to build a printer with access only to common analog tools. I chose Czibesz's version because I was pursuing the notion of printers being self-replicating. Since approximately only 1/3 of the components was actually 3D printed or CNC milled, I might be more inclined to fabricate a variation of Keep's original printer in the Global South.

36 Arduino is an open-source electronics platform based on easy-to-use hardware and software. (Arduino 2018)

37 Special thanks to Gerald Grison for patient IT support and guidance.

38 Research included documenting variables however, since all variables are subject to specific claybodies and viscosity, data remains pertinent only to this author's research.

39 Unlike Cartesian style printers which can be built for mobility and are capable of building large-scale architectural structures in situ, the Delta style printer is less adaptable for mobile functions and is better suited to discrete objects that can be removed from the print bed.

[40] See Appendix C for future research.

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# Appendix A: Abbreviated Table of Variables

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Cura<br>Nozzle size | 14 gauge (g) | 14 gauge (g) | 14 gauge<br>cut slight angle | 14g snipped<br>approx. 13g? | 14 g snipped<br>approx. 8g? | 14 g Snipped<br>Approx.. 8g? |
| Cura<br>Print speed | 28 | 28 | 23 | 20 | 15 | 20 |
| Cura<br>Infill speed | 40 | 40 | 23 | 20 | 15 | 20 |
| Cura<br>Layer Height | 1.5 | 1.5 | 1.5 | 1.6 | 2.1 | 2.3 |
| Cura<br>Flow | 600-800<br>(+?) | 600-800<br>(+?) | 800-1000 (+?) | 800-1000 (+?) | 2000 | 2000 |
| Cura<br>Material diam. | 1.0 | 1.0 | 1.0 | 1.0 | 2.1 | 2.3 |
| Cura<br>Wall thickness | 3mm | 3mm | 3mm | 2mm | 3mm | 2.3 |
| Cura Jerk | ? | ? | | | 15 | 15 |
| STL<br>Mesh settings | default | default | 0 0 0 0 0.5, 0 | 0 0 0 0 0.5, 0 | 0 0 0 0 0.5, 0 | 0 0 0 0 0.5, 0 |
| Air pressure | 4-5 bars | 4-5 bars | 4-5 bars | 4-5 bars | 4 bars | 4 bars |
| Clay Viscosity | Soft clay<br>Not paste | Peanut butter<br>paste | Peanut butter<br>paste | Peanut butter<br>paste | Peanut Butter<br>firm paste | Peanut Butter<br>firm paste |
| Drying outcome | (uncovered) | (uncovered)<br>Cracked<br>crumbled | (uncovered)<br>Stuck to bat. Ok if loosened at leather hard | (uncovered)<br>Some cracking of bottoms – too thin | Covered<br>Complex forms need loosening at leather hard | Covered<br>Complex forms need loosening at leather hard |
| Firing results<br>cone 6 | Good. No unforeseen cracks | Good. No unforeseen cracks | Good. No unforeseen cracks | Good. No unforeseen cracks | Good. No unforeseen cracks | Good. No unforeseen cracks |
| Observations | Nada. Nothing coming through. Might have also been the extruder. Will test firmer clay again | Chattering persists.<br>Speed weirdly variable.<br>Layer height too short, dragging itself in the clay.<br>Clay oozing from top of extruder.<br>Not enough clay at high speed. | Chattering eliminated by simplifying STL.<br>Speed variable eliminated.<br>Angle nozzle slices through layer… ok if taller layer?<br>Benefit = compression of layers?<br>Wall too thick.<br>Jerk seems too high TBD<br>Detail very low. | Chattering eliminated.<br>Speed variable eliminated.<br>Layer thickness good.<br>Compression still ok?<br>Wall thickness better<br>Jerk seems too high TBD<br>Detail very low. | -SPIRALIZE OUTTER CONTOUR is key to printing complex shape!<br>-Using Surface Mode NORMAL.<br>-Print Sequence ALL AT ONCE<br>-All SPEED settings same<br>Loosened auger to allow air to escape. | Same as (E)<br>Auger screws stripped, bound with wire.<br>Balancing viscosity, air pressure, flow rate, nozzle size, tightness of wire connecting auger to motor to allow air to escape without too much clay squishing out. |

# Appendix B: Selected Up-cycled/AM Products & Social Enterprises

1. *Circular Ocean* (Circular Ocean n.d.)
2. *Darn Good Yarn* (Darn Good Yarn n.d.)
3. *FAB City Project* (Initiative 2018)
4. *Field Ready* (Field Ready n.d.)
5. *Futurecraft 4D* (Addidas 2016)
6. *ONO smart phone 3D printer* (ONO n.d.)
7. *Parley* (Parley; for the Oceans n.d.)
8. *Perpetual Plastic Project* (Better Future Factory 2015)
9. *Pinatex* (Ananas Anam n.d.)
10. *The Plastic Bank* (The Plastic Bank n.d.)
11. *The Responsible Fabric Firm* (B the Change n.d.)
12. *Trochet: Upcycled Plastic Bag Furniture & Yoga Mats* (Lisa 2014)

# Appendix C: Ongoing Research

## Minimum Requirements for Successful Dissemination of AM in the Global South

Additive Manufacturing hardware must become more accessible

1. Designs must include iterations of appropriate technology for any level of economic development
2. Hardware and software should be adapted for use with ubiquitous smart phone technology.
3. Open-source 3P printer models should focus on use of E-waste in new hardware and must themselves follow Regenerative Design principles.
4. Software must be accessible, open-source, available in multiple languages and intuitive so that barriers to uptake are decreased.
5. Additive Manufacturing Education must to be intentionally disseminated:
6. Education of the benefits of AM must not be limited to possible economic gains as this may perpetuate current global value chains
7. Regenerative Development principles must be attached to the dissemination of AM technology.
8. Development work must be recognized as an opportunity for reciprocal learning and employ mutually beneficial, train-the-trainer models of information sharing

## Questions for Future Research

1. How circular in nature is the RepRap? What happens to the components of all these spent machines? Are they Upcycled, Up-cycled, Recycled or Wasted?
2. How, if at all, will 3D printing and the RecycleBot change our concept of down-cycling, recycling and/or upcycling?
3. How can Upcycled materials be used in Additive Manufacturing? (i.e. 3D printing with paper pulp)
4. How will 4D printing, robotics and artificial intelligence impact these concepts? Will this current research all be obsolete within a decade?