Chapter 9

A Generative Perspective on Engineering: Why the Destructive Force of Artifacts Is Immune to Politics

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Engineering is closely tied to social and environmental destruction across the globe. The energy industry has created global warming, oil spills, acid rain, and toxins ranging from mercury to radioactive waste. Manufacturing has turned skilled crafts into low paid, repetitive assembly jobs. Information technology has accelerated wealth inequality such that the top 1% of the world's wealthy now own 50% of the wealth. One theory is that these detrimental effects have nothing to do with the engineering design; that they are merely the result of how capitalism forces us to use otherwise "neutral" technologies. But socialist experiments from the USSR to Venezuela have shown the same degree of pollution and poverty as capitalism. "The People's" radioactive waste left over from the USSR will kill you just as fast as General Electric's radioactive waste in the US. *The destructive force of artifacts is immune to politics*. However that is because both left and right ends of the political spectrum have focused on systems built for the extraction of value. A generative approach to engineering, in contrast, would design technologies specifically for maintaining value in unalienated forms, and circulating that value rather than extracting it. This paper will review this underlying concept of generative justice, and how that can be adapted to engineering practice.

9.1 Labor Value, Ecological Value, and Expressive Value

Elsewhere (Eglash and Garvey 2014; Kuhn 2016; Eglash 2016a, b), we have explained generative justice by starting with examples of indigenous cultures. In the traditional communitarian economy of the Iroquois for example, an

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“agroecology”—the three sisters of corn, beans, and squash—had dramatically higher yields than European plow methods of the day (Mt Pleasant 2006, 2011). Bean root nodules contain nitrogen-fixing bacteria that help corn and squash; corn provides vertical support for beans; squash’s broad, spiny leaves prevent soil moisture loss, weeds, and pests. The soil agroecosystem was so effective that Euro-American farmers who annexed their land in 1804 reported initial yields of 80 bushels per acre. By 1845 yields had dropped to 26 bushels per acre; without the Iroquois ecosystem, the soil was rapidly depleted. Even today, artificial pesticides and chemical fertilizers fail to achieve the long-term effects that agroecosystems make possible (creating, for example, pesticide “treadmills”).

It is easy to understand, in the case of soil depletion, what is meant by “value extraction”. A flow of things that have value with respect to ecosystem flourishing—nutrients, physical features, hydration—move in a cycle. Human harvests by the Iroquois were part of that cycle. The Euro-American farmers extracted value rather than cycling it. Once extracted and sold for cash, we can say the value was “alienated”—converted to a form the ecosystem cannot use. Other examples of ecological value extraction include overfishing, unsustainable logging, and so on.

The concept of “value alienation” is most closely associated not with ecological value, but rather with Karl Marx’s analysis of labor value. In his 1844 “comment on James Mill”, he asks us to imagine a traditional artisan whose pride in excellent crafting skills and pleasant social ties in a precapitalist village provide the greatest satisfaction in life; here “the act of labor itself is for him the enjoyment of his personality and the realization of his natural abilities and spiritual aims.” Marx later used the Iroquois specifically as an example, since Lewis Morgan had documented how their relations of reciprocity, communal sharing, and gift-giving ensured unalienated labor value circulation.

Marx contrasts that vision of traditional artisanal satisfaction with the physical, financial, and psychological deprivation of low-skilled workers in industrial factories: the worker has become alienated from their product (one cannot take pride in having repeatedly inserted screw #17 on the assembly line all day); alienated from their work process (see “assembly line”); relations with users (who might not buy the product if they could see the suffering attached to it); and even their own bodies (e.g., repetitive strain and industrial toxins). From Marx’s point of view, the labor value that one could have invested in meaningful artisanal work has now become alienated from the worker.

Although Marx was primarily focused on labor value, some of his remarks on soil depletion show that he was aware that ecological value was also circulated in traditional societies. And although he had no category for it, he occasionally mentions what I would place in a 3rd category, that of “expressive value”. The Iroquois, for example, had voting for women centuries before any European nation. Like most Native American cultures, they provided a legitimate role (“Two Spirits”) for people we would consider gay, lesbian, bisexual, and gender-variant. And while neither Marx nor the Iroquois might recognize them all, most of the things we consider protected by civil rights in our era—free speech, the right to be an atheist or practice a religion of your choosing, free access to knowledge, love for

people and places, and so on—would also be examples of expressive value. Like labor value and ecological value, the generation of expressive value also best flourishes when it is freely circulated, and can be extracted to the detriment of those who generate it (think, for example of the ways religious faith is extracted for political gain).

In all three cases—labor value, ecological value, and expressive value—the promise that capital makes (“no worries, we will return that value back to you in the form of money”) is a false one, because once systems of work are designed to maximize the extraction of value—mass production, deskilling, “externalizing costs” such as health and environment protections—the damage has already been done, and buying commodities to compensate merely immerses us further in alienated products.

Marx thought that taking capitalism out of the equation would solve the problem, but he was mistaken. One of the best sources for this comparison is sociologist Burawoy (1985), who carried out participant observation studies as a factory worker in the manufacturing industry in Chicago, and similar plants in communist Hungary and the USSR. As a life-long dedicated Marxist, he had no personal inclination towards reporting the negative side of state socialism, so his critiques are all the more convincing. In both capitalist and communist industries he found similar deprivations—dangerous environments with limited safeguards; low pay; and his main focus, forms of coercion that keep people working hard. The methods of coercion were different but equally damaging: “each system has its own rationalities and irrationalities, and each fashions workers who adapt to or resist those (ir)rationalities” (Burawoy 2006, p. 65).

Rather than extract value and centralize it for later redistribution, it is possible to have a generative economy: leave value in unalienated form, and circulate it through a commons. Hence the definition of generative justice (Eglash 2016a): *The universal right to generate unalienated value and directly participate in its benefits; the rights of value generators to create their own conditions of production; and the rights of communities of value generation to nurture self-sustaining paths for its circulation.*

Marx thought that extraction and centralization would be required for high-tech societies; the generative ideal would only be possible for low-tech indigenous societies. But generative cycles are indeed possible in high-tech circumstances as well: open source computing is a common example. The challenge is that since we are starting from an extractive economy, it is hard to kick-start an entirely new mode of living: for example if you give away code for free, how do you make a living?

In Eglash (2016b), we provide an example of such a transition in the case of Arduino, an open source microprocessor (Fig. 9.1). We have visualized the flow of value in two ways. When alienated it appears as a single line; when unalienated as double lines. In the upper left quadrant, we see mass production of computer chips as the extraction and alienation of labor value as Marx envisioned it: low-income workers with little benefits or pay. In the lower right we see unalienated value flow without income; the Internet “gift economy” of makers. But in the upper right, we see a hybrid cycle in which both the gift economy and realistic income converge.

Fig. 9.1 The links between extractive and generative flow in the Arduino ecosystem

This example is a modified Arduino board, the circular LillyPad created by Leah Buechly to reduce gender barriers to DIY electronics and computing. As a for-profit company, it is creating income. But as part of the gift economy, its design and code is open source, and users freely give away their designs to a commons, from which they too benefit. In Eglash (2016b), I have detailed many examples of such beneficial social relations embedded in the Arduino ecosystem—in particular, social justice and environmental sustainability projects—and the ways that have enabled other instances of this “third cycle” in which a gift economy is linked to forms of “social entrepreneurship”.

The Arduino ecosystem is not an independent generative economy. It is still tied to exploitation of labor and nature in some of its electrical components in the upper left quadrant, and even the other two are still vulnerable to problems such as sexism in makerspaces (Dunbar-Hester 2016). But it creates a clear goal for the transition to generative justice: shrink the upper left quadrant and expand the two on the right. What kinds of engineering practices can contribute to that pathway? What kinds of engineering opportunities do we need to be attentive to when asking how we can replicate such cycles elsewhere? The next section will examine both historical and contemporary case studies.

9.2 Watchmaking

There have always been generative alternatives to extractive forms, and they do not all lie in a low-tech indigenous past. For example, in 1872 Russian scientist Peter Kropotkin traveled to the Jura Mountains in Switzerland. The communities in the region were famous for having defended their industry against corporate takeover

by the pressures of mass production, which was turning out cheaper (and lower quality) products elsewhere. And yet they also defended the autonomy of groups within the International Workingmen's Association (IWA), rejecting an attempt by Karl Marx and his followers to turn the IWA general counsel into the central authority of a political party. What power could be hidden in these small towns that could withstand the pressures of both right wing and left wing authoritarians? Kropotkin (1899) writes:

In a little valley in the Jura hills there is a succession of small towns and villages, of which the French-speaking population was at that time entirely employed in the various branches of watchmaking. ...The very organization of the watch trade, which permits men to know one another thoroughly and to work in their own houses, where they are free to talk, explains why the level of intellectual development in this population is higher than that of workers who spend all their life from early childhood in the factories. ... The egalitarian relations which I found in the Jura Mountains, the independence of thought and expression which I saw developing in the workers... appealed far more strongly to my feelings; and when I came away from the mountains, after a week's stay with the watchmakers, my views upon socialism were settled. I was an anarchist.

I selected the Jura example because this volume is dedicated to a conversation between engineering and social science. Illustrating the concept of unalienated value with indigenous culture seems like something that appeals best to anthropologists, but I hope that watchmaking is an example of unalienated value can speak to engineers: the material and intellectual demands for precision, metallurgy and mechanics; what Csikszentmihalyi (2000) refers to as the mental state of "flow" during a skillful crafting experience; pride in design innovation; and respect for independent, rational thinking. Beyond individuals, the collective social dimension here is quite significant. Kropotkin immediately saw the critical role that was played by workers in charge of their own production environment; in particular the role of "expressive value": free speech and inquiry, intergenerational relations of caring (Folbre 2014), and other features were cycled within this network as well. Veyrassat (1997) compares the success of Jura watchmakers to the failure of the calico-printing industry in yet another Alpine valley in Switzerland during this same time period. She shows that the calico printers attempted to preserve wages and working conditions by passing laws against innovations such as "double printing"; in doing so they became vulnerable to advances elsewhere. In contrast "the watch industry was to set out on the path to a modernization that did not break with the indigenous manufacturing model" (p. 201).

Auerswald (2017) points out that the Jura watch tradition did not stop there: In 2014 China exported 669 million watches; 20 times that of Switzerland thanks to the role of automation and robotics. Yet robot profits did not exceed those of highly skilled humans: At \$24.3 billion, the Swiss watch industry made 5 times that of the Chinese. On the other hand, contemporary Swiss watchmaking is no longer the province of working class artisans. Auerswald is not insensitive to this issue; he points out that the American company Shinola, located in Detroit, imports Swiss watch parts and assembles them into American-branded casing. He cites this

example—a new company birthed in the very city that symbolizes American manufacturing decline—as vindication for his thesis that the increasing abstraction of technology—the tendency to move from physical mechanism to code—spontaneously creates new entrepreneurial niches, due to “an inexorable evolutionary logic that constantly shifts the landscape of opportunity”.

What Auerswald fails to note is that Shinola’s location in Detroit was part of a carefully calculated marketing strategy. Muller (2013) describes how Texas billionaire Tom Kartsotis first did marketing research. He discovered that a luxury item branded as “made in Detroit” made the product attractive enough to compete against luxury imports; he then purchased the Shinola name from the defunct shoe shine company to add a nostalgic aura. As Perman (2016) puts it,

With Shinola, Kartsotis has performed a near magical marketing act—creating an artificial heritage brand by co-opting others’ rich American histories. ...Shinola’s products are designed and packaged with an American midcentury look, evoking nostalgia for a bygone era of quality and integrity. Most important, by hatching the brand in Detroit—a city emblematic of American hardship, resilience, and craftsmanship—the brand is selling more than watches; it’s selling a comeback. Every time customers in Neiman Marcus or Saks purchase one of the brand’s \$850 watches or \$300 leather iPad cases, they too can feel like they’re doing their part in Detroit’s fight for survival.

In other words, Auerswald has it backwards. It is not an “inexorable evolutionary logic” of progressive technological abstraction that spontaneously created a new job niche, and they just happened to locate it in Detroit. It is because Kartsotis and his market research discovered they could tap into a yet-to-be-exploited source of expressive value: the human desire to love our cities despite their decay; to root for the underdog; to live a morally acceptable life. And our human fears too: our feeling that as rich Americans wearing a luxury European brand we might be seen as traitors, while wearing an American brand—even one made from Swiss parts—will make us feel good about ourselves, because we see ourselves through the eyes of others.

Using the colloquial term “bougie” [boo-zhee] for bourgeois, professor of design Modrak’s (2015) insightful essay titled “bougie crap” examines the contradiction between the working class cultural capital that Detroit represents, and the lack of return value flow to the working class in the case of Shinola. She attributes that in part due to the product itself (hence the title), and in part the resulting gentrification:

Start with a neighborhood or city that lacks economic incentives or that is populated by minority groups, which are underserved by municipal services including education, transportation, street lighting, police response time and maintenance. Enter a mainly white, middle-class population. Investors clamor to underwrite new businesses, sponsor grants or to secure real estate. This triggers a spike in real estate prices and a flood of new commercial ventures that sell expensive bougie crap that only the new residents can afford.

I do not mean to be dismissive about the gamble Kartsotis made in locating in Detroit, or even the idea of tapping into such wellsprings of expressive value. Rather, we should focus on the missed opportunity to return value to those who generated it. As a counterexample, consider Bachinger’s (2015) analysis of the

I find that such possibilities for synthesis are too often answered with relatively minor tweaks: perhaps Shinola offers to add donations to some local charity, or VinziRast adds a cell phone app for ordering. Haraway's (1991) cyborg metaphor is a useful starting point for dismantling the barriers that keep this divide in place. She notes that creating a divide in which social justice and sustainability are pushed to an organic, low-tech side, and naming "the enemy" to be everything on the other side ends up reproducing many of the misleading assumptions that caused the problems in the first place. Authoritarian claims for "the natural" are common in the history of injustice: when LGBTQ people are accused of "unnatural sex" or interracial relationships are seen as violating national purity and its union of "blood and soil" we witness the negative consequences of the natural/artificial dualism. Instead Haraway urges us to recognize that humans are "always already" part artificial: our jaws evolved to their present tiny size because we invented fire; our immune systems have been reprogrammed to ward off polio, diphtheria, and other deadly diseases; everything deeply human about us, from language to clothing to shelter, draws as much from the artifice of innovation as it does from nature. That is not to say that making something "more cyborg" automatically makes it more just or sustainable; rather it is a call for considering multiple paths that do not exclude the cyborg options.

9.3 A Cyborg Path to Generative Justice

One of the pressing issues of our historical moment is the dramatic increase in automation, from AI to robotics. Auerswald's above discussion of watchmaking was intended to address that issue in two ways: first, he claims that tasks which tend to be more human-centric (in this case high-end luxury watch crafting, but he also mentions waitress, cook, actor, etc.) will always provide a safe economic refuge, even against automation challenges. Second, he claims that automations' encroachment spontaneously creates new economic niches, and some of those will be suitable for exactly those human-centric tasks. I hope the description of Shinola's marketing strategy above provides a useful counter to the second claim: markets are strategically created, not simply handed to us by inexorable techno-evolution, and the available strategies are increasingly in the hands of the already-wealthy. As to the first claim, I will offer a counterargument from Noble's (1986) analysis of General Electric's (GE) experiments in replacing skilled machinists with numerically controlled (NC) machine tools—automated devices that shaped metal according to a computer program—during the early 1960s.

Nobel shows that the tools were not the simple result of superior technology replacing inferior humans: the machinists' hand-guided product was, during the initial years, superior to that of the NC automation in both quality and quantity. Rather it was a deliberate strategy to break labor union shop floor control, and enhance "Taylorism" in which workers behavior is strictly controlled from the top down. Putting computer programmers in charge of NC tools was an attempt to put

shop floor production in the hands of a white collar task (coding), a natural alliance with management, leaving the machinists as deskilled machine button pushers. But an important objection to Noble's account was raised by Pickering (1995).

Picking begins by citing Haraway, noting that the machinists and their tools already formed a "cyborg" pairing prior to NC automation. In his language, when human agency interacts with machine agency they always form a "mangle" of the two, and any destabilization—introducing new technologies, social formations, etc.—will always contain an element of unpredictability; a "dance of resistance and accommodation" as human intentions and nonhuman forces negotiate until re-stabilization occurs. He notes that Noble's own analysis—the Marxist claim that class domination will always be the overriding force, even above profits or productivity—failed to predict what happened next. Once the poor quality of NC tool production was made apparent, GE management attempted the usual set of rewards and punishments to fix the problem. When that failed, they made a desperate move: a pilot program put these workers in charge of production.

A radical experiment in worker control given the context, GE's new Pilot Program would be "unique in that there was to be no foreman, no scheduled lunch periods, and flexible starting and personal times." (Nobel 281). The generative opportunity was not lost on workers: machinists began to "schedule equipment start-up; work with planning in developing, implementing, and controlling new methods and procedures; approve programming from the viewpoint of good machine shop practice; review and make suggestions about changes in workstations, tools, and fixtures; assume responsibility for quality in the unit and interface with quality control; [and] monitor the area for availability of all materials and check equipment to insure safe and proper functioning" (280–281). Production and quality dramatically increased. As newly empowered workers began to clash with management, GE administration concluded that the risks were now exceeding their benefits, and enough had been learned to reestablish the older managerial style.

From Pickering's view, this shows that his framework of the emergent human-machine "mangle" offers a better understanding, because the worker-controlled production, even if only temporary, was unpredicted. From Noble's view, the fact that managerial dominance was eventually reasserted proves his Marxist framework; the momentary contradiction was merely a sham for duping workers into exploiting themselves. But I want to draw out a third possibility by comparing the GE pilot program to a strikingly similar event happening at exactly the same time period on the other side of the iron curtain. In 1968, many factories in Czechoslovakia also began to experiment with worker control.

The backdrop of the Czech experiment is always described in political terms, and for good reason. At the end of WWII, Czechoslovakia was the only nation that voluntarily voted to be on the Soviet side, and they naively thought that they could create their own vision for communism. The "Prague Spring" of 1968 saw a brief liberalization in many domains: fewer travel restrictions, less censorship, more consumer goods. The brief rise of worker-controlled factories is usually seen as a purely political outcome of this movement. But there was also an undercurrent of the same internal engineering critiques that plagued GE regarding parts quality.

The communist version of Taylorism (in the USSR promoted by *nauchnaia organizatsia truda*, “the movement for the scientific organization of labor”) was similar to GE’s top–down control methods. In a 1968 speech promoting the worker self-management movement, one of the engineers described a similar disappointment in the quality of machined parts:

When we steel workers pointed out that we were turning out steel for the scrap heap, they nearly put us in jail because, they said, we were throwing mud at our socialist industry. ... Aren’t you ashamed,’ they said ‘you’re steel workers and you criticize the steel concept. You’re reactionaries.’ Only I don’t have to be dumb just because I’m a steel worker. (Vítak 1971, p. 251)

The generative alternative for both GE factory workers and Czechoslovakian factory workers ended by different methods: at GE, they simply reasserted the old top-down management, whereas in Czechoslovakia, half a million Warsaw Pact troops and tanks invaded the county. But I hope readers can also see the underlying similarities (Fig. 9.3). Whereas Noble’s Marxist analysis positions the generative moment as an all-too predictable capitalist ploy, and Pickering sees it as evidence of the inherently unpredictable emergence, a generative perspective would view it in terms of movements along a dimension *orthogonal* to the left/right political spectrum. The question is then how to nurture the movements along that vector, adapting to the unavoidable contingencies.

9.4 Tuning for Generative Justice

“Tuning” is Pickering’s term for the series of adjustments that occur as human and machine agencies re-stabilization. I think Pickering is right about the unpredictability engendered by such a “dance of agency,” but a generative perspective

Fig. 9.3 Generative justice as orthogonal to the left/right political spectrum

can adopt that as a positive attribute; a means of exploring the potential design space. Our experiments in this area are often with indigenous groups, and when introducing our design process I frequently use the metaphor of plant roots and water. When water enters soil it undergoes percolation, trickling through whatever grains of sand or crevices offer the path of least resistance. Plant roots take a similar search, growing along whatever hints they can sense in the earth. Eventually, water and roots meet up.

In similar ways, we try to avoid the stereotype of “clever engineers here to solve your problem,” or the reverse trope of fragile indigenous cultures who will be tainted by any change. Rather, each side needs to explore the space of possibilities, find meeting points where root and water intersect, and investigate the potential consequences. Reducing indigenous knowledge to a western translation is not sufficient; a recursive transformation is required (Lachney et al. 2016a). We need concepts that become more compelling with advancing knowledge, not less so; but even something like Haraway’s “sympoiesis” cannot stand on its own. We to help engineers tune their work to the self-generating key of life, and that would not happen in the tone-deaf training camps we call STEM education.

STEM education is increasingly turning to bottom-up structures, and yet these often fail to offer generative justice because they ignore value alienation. Consider, for example, MIT’s Scratch program in which children learn coding to create their own games and animations. Our recent study (Lachney et al. 2016b) showed 2960 occurrences for “Barbie,” 6530 results for “McDonalds”; 4600 for “Disney Princess”; 8210 for Transformers; “17,400” results for Call of Duty; and over 3 million search hits for “Pokemon.” The Scratch website’s motto: “We turn children from consumers into producers.” Marketing and media has colonized children’s lives. For the last decade, our group at RPI has been creating alternative forms of STEM education using simulations of Navajo weaving, cornrow braiding, urban graffiti, and other practices that can empower children with their own heritage, rather than the lesson that both science and art all come from the colonized world (www.csdt.rpi.edu). As these simulations get picked up elsewhere, we have learned more about cycling unalienated value back to its source of generation, which I will illustrate with the following example from our work in Ghana (Babbitt et al. 2015).

When I said we needed concepts that become more compelling with advancing knowledge, and not less so, I did not mean to suggest that atheism is better than spiritual practices; rather it is a question of contextualizing these guiding principles in ways that advance both Technoscience and indigenous partners. In our work to establish an indigenous basis for engineering in Africa, we began with adinkra, an indigenous stamped textile practice that uses symbols representing spiritual concepts such as the life force present in all living things, reconciliation with enemies, etc. Adinkra ink is made from the bark of the Badie tree, and areas in which the bark is extracted suffer less deforestation. Our first intervention was using solar energy rather than firewood to cook the ink. The second was using the adinkra symbols themselves in math and computing education; combining virtual forms with a hands-on practice that helps increase employment for ink makers and symbol carvers. The virtual form was burned to CDs for local sale. Adinkra was also used

for HIV prevention. We began with surveys that indicated embarrassment at point of sale was a barrier for condom use. The inspired a project in which New York and Kumasi mechanical engineering students collaborated on the development of a locally produced condom vending machine. Adinkra artisans created an exterior to add local aesthetics. And an e-waste “upcycling” program was introduced to supply parts for both the condom machine and the computing education program.

Figure 9.4 shows the flows of value described above. Some of the engineering was quite sophisticated; for example, the local team in Ghana wanted to add 3D printing for the gears in the vending machine using recycled plastic. They are now adapting the design to fit pregnancy tests and reproductive health kits. A pessimist might assume such approaches are doomed to be restricted to small-scale enterprises or remote villages. To provide a counter example, we can look at how our indigenous simulations have been taken up by architects attempting to improve the environmental and social characteristics of large-scale buildings (Fig. 9.5).

At the same time, little of this was intuitive for the engineers involved. We need to stop training engineers to ask “what do people want”—an answer which will be conditioned by their training in capitalist extraction of value and colonization, as we saw in Scratch—but rather training them how to research and recognize unalienated value; to engineer solutions in which that value can be nurtured and circulated; and develop systems that put those who generate the value—humans and nonhumans alike—in charge of its production.

Fig. 9.4 Unalienated value flow in engineering projects in Ghana

Fig. 9.5 Indigenous fractals in contemporary architecture (from <http://blog.ted.com/architecture-infused-with-fractals-ron-eglash-and-xavier-vilalta/>)

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