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The Future is Fabulous: Digital Fabrication, Datascaping, and Design Futurism

Video stills from *Z-Printer 450 Introduction* (Z-Corp, 2007).

A bright orange, plastic panel with a small digital menu and a big black knob; a man's hand dials the knob through various menu options.

He sits in front of a nondescript computer monitor in blank white surroundings, wearing a blue-collared shirt and khakis—the "business casual" uniform. On-screen he rotates a three-dimensional digital model of some machine part in virtual space. The plastic panel belongs to a large machine; it is glossy and grey with a wide, stainless-steel handle.

More machine parts in hyper-color revolve on screen as he sifts through the collection, looking for the one he needs. He adjusts the model and clicks OK. Our friendly office worker approaches the printer and lifts its enormous lid, which swings back more easily than its size would suggest. He loads an enormous cartridge into the printer, hooks up a bucket, and finally pops in another smaller cartridge, just like those in the inkjet next to me on my desk.

A large print arm lays down colored lines—some kind of cross section—on what seems like white paper. Suddenly the plane drops away; it isn't paper at all, but delicate white powder draining out the bottom of a mechanical chamber. The machine part

remains, ghostly white and looking like a little boy's toy ray gun. His hands inside an incubator-like chamber, the office worker holds the ray gun gingerly in his left hand. He aims a nozzle, blowing the white dust away with compressed air. The air cleans the ray gun, revealing its cartoon-colored surface. He removes it from the chamber, submerges it in a bowl of clear liquid, brushes it with the clear liquid, and applies the liquid with a squeeze bottle to make sure he coats it thoroughly. The object emerges saturated and shiny.

Now he stands by the machine in an office, co-workers nearby in their cubicles. The printer stands shoulder-height and an arm's span wide, about the size of a large office copier. He lifts the lid, removes the snappy little ray gun, lowers the lid again in one smooth motion, and walks off.

What I've just described in all its dazzling blandness is an advertisement for a Z-Printer 450, a "rapid prototyper," "digital fabricator," or, more colloquially, a "fabber."[1] Fabbers combine information and fabrication technologies to construct objects, one at a time, from digital plans. They generate a three-dimensional form the same way a printer creates a flat image on paper, building up one tiny cross-section after another. Their similarity to printers has produced another name, "3D printers," a term that especially suits the recent crop of machines which fit and function easily within an office, rather than an industrial model-shop or factory.

Allying fabbing technology with the idea of printing seems fitting and exquisitely convenient. Whether at home on a toaster-size inkjet or on a massive industrial press, printing is a technology even most technophobes have come to value (and one we see as central to our development as a Modern culture). Fab's adoption of the metaphor provokes consideration of the similarities with printing's evolution into a personal-production technology and the resulting relocation and redefinition of graphic design practice.

However, extruding this familiar and comfortable production model beyond visuality into materiality doesn't segue perfectly. Fabbers' production of singular, complete objects (rather than a series assembled from mass-produced components) begins to engender a very particular conception of production. That we could make everything we need or want for ourselves feels anachronistic, and the idea that I could print a teacup or a chair retains an aura of science fiction, if not outright magic.

The Z-Printer ad also demonstrates the technology's social and human component by showing us an individual interacting with it, a first step in considering the socio-technical paradigm of fabbing. It recognizes that technological and social spheres are perpetually connected, each influencing the other's development. French sociologist Bruno Latour explains the connection between the technical and the social sphere of our existence: "There is no sense in which the notion of a human can be disentangled from the nonhuman into whose fate it has woven more and more intimately over the ages."[2] Within the cultural sphere, visual and narrative forms inspire and are inspired by this emerging production technology. Even the most mundane portrayals allude to science fiction, for example, by printing a ray gun. Others, like the futuristic depictions of object-making on television and elaborate utopian schemes peddled by fab's inventor-evangelists, display their sci-fi qualities more overtly.[3] Collectively these visualizations, along with the trajectory of this technology's development, suggest that digital fabrication

Bone Chair by Joris Laarman (2007). Aluminum chair created using three-dimensional printing.

will change our relationship to production as both consumers and designers.

The future projected by fabbing won't mirror the science fictions and speculations put forward by its developers. Those fantasies about the future of object-making rely both on a control of matter theoretical physicists only dream of and on unlikely technocratic social utopias.[4] Instead, we ought to imagine fab's potential overlaid on our current productive social and technological norms. Narrative science fiction and projective futurism part ways here. Sci-fi rhetoric fails to offer real models of how product design might change as the practice moves away from trained professionals and enters the purview of individuals. For a more realistic scenario of how fab will change product design, we can look to transitions that have already taken place as digital production entered other areas of design, particularly the localizing and specializing effect of the advent of desktop publishing on graphic design practice.[5]

To understand how digital fabrication changes consumer-product relationships, it is helpful to look carefully at the current paradigm. For the most part, users of globally manufactured goods maintain a total, unfragmented experience with products. Increasingly, the products we employ don't even contain functional "parts" in any intelligible sense. Instead they contain circuits, sensors, and displays; they are composed of a multitude of polymers and intricately articulated parts molded to fit seamlessly, as if born whole instead of assembled in a distant factory. These things (and our experience with them exclusively as whole objects) lend themselves to digital fabrication; we don't need to access or even see their insides. Science fiction author and sometimes-futurist Bruce Sterling describes these

"blobjects," as he refers to them: "Unlike classic twentieth-century industrial objects, their form does not follow their function. That's because their functional parts, being chip-based, are too small to see. Form can no longer even see function, much less follow it."[6]

These products distinguish themselves from classic twentieth-century designs in other ways, too. In the early twentieth-century, proliferating industrial production demanded standardization so that mass-produced objects and components might work together. As a result, standardization became a design principle. During the 1920s and '30s, as product design emerged as a profession, designers viewed their audience as an undifferentiated mass of consumers ripe to accept the products intended for them. Advertising relied on this mass identity, selling consumers on the idea that being American gives one the right to the same products as everyone else. But in the latter half of the twentieth century, the explosive growth of advertising and mass media drove designers and marketers to appeal to broader, more diverse, and increasingly economically empowered populations. Expanding their efforts, manufacturers began to distinguish and target differentiated groups. Producers could not only sell to more people this way, they could charge a premium for more directed products that seemed to respond to specific needs and desires. This shift marks the germination of a trend toward product customization.

Very recently, advancing information and communication technologies have facilitated an enormous expansion of the possibilities for product customization.[7] The economies of scale that make mass production advantageous (including materials, space, time, and labor) have fused with the needs of ever-more refined consumer segments. Technologies like barcodes, RFIDs,[8] and satellite tracking make it feasible to manufacture, transport, inventory, and sell an unprecedented profusion of consumer goods. The concentration of transnational capital (and neo-liberalization of global finance), off-shoring of materials extraction and manufacturing, continual surveillance, and the ability to store and administer huge quantities of data on consumer behavior have helped amplify production while purposely distancing it from consumption.

In choosing from the astounding array of available products, choice itself becomes commodified. The shelves of big-box stores and neighborhood boutiques brim with row upon gleaming row of consumer products. But our remoteness from production and lack of control (or even understanding) of the things made for us sometimes leads to discontent, even as we relish the privilege that distance and choice afford. Design critic Claudia Donà argues that the proliferation of products has done little to fill the void created by mass marketing's attempts to sell them to us:

> *[W]e live in a world overflowing with our own productions, a world in which objects besiege us, suffocate us, and very often distance us from one another both physically and mentally. We are compelled, by the pervasive sameness of these objects, to respond to them with the same gestures: they make us forget how to feel, to touch, to think.*[9]

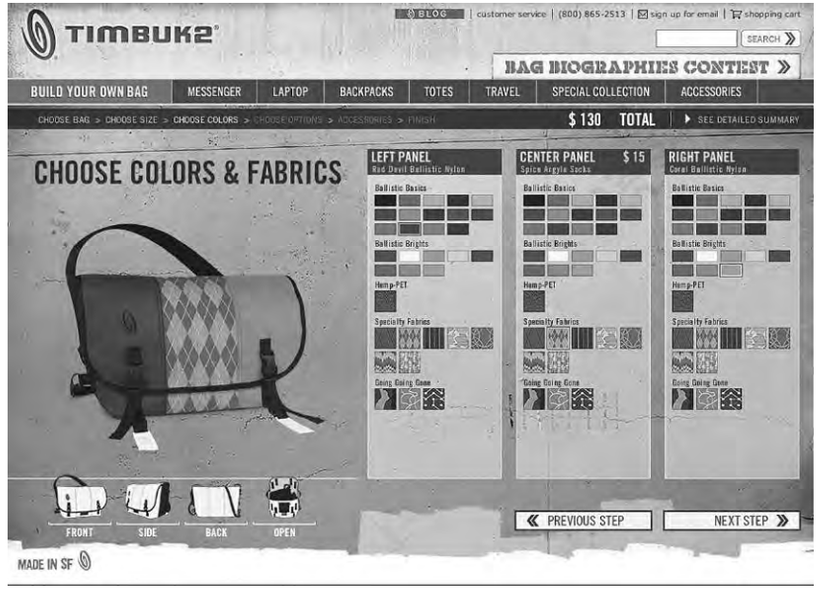
Products—or more precisely, choosing products—define us as social beings within contemporary consumer society. Sociologists Mihály Csíkszentmihályi and Eugene Rocheberg-Halton, in *The Meaning of Things: Domestic Symbols of the Self*,

find that people make meaning in their lives by curating collections of manufactured products rather than by making things (or even acquiring unique objects): "By and large, we now define ourselves through objects of consumption rather than production,"[10] Without a hand in actually making these objects, we find other ways to make meaning with them.

Yet many products seem utterly banal, incapable of symbolizing any sense of self. Around our classrooms, offices, supermarkets, and airport lounges, we easily spot our mobile phone in another's hands or someone else donning the same shoes. Other objects seem more attuned to us as individuals: a hairbrush that combines my love for unvarnished wood with just the right kind of bristles arranged around its barrel. Products we can actually take part in forming seduce us further: the process of "customizing" our belongings, even in the most superficial ways, instills commodities with personal meaning. We can choose the color and patterns on the roof of a MINI Cooper, or rearrange features on a Timbuk2 messenger bag. In so doing, we construct individualized consumer subjectivities for ourselves, or, at least, we believe we do.

Even those products we think of as personalized or customized continue to share some essential commonalities with all other mass-manufactured goods. They reflect a complex matrix of social and economic factors. Success in product design and marketing depends on uncovering trends and similarities in people: their real and perceived needs, and their overt and latent desires. These professions create things that, while mass produced, seem to target individuals. These products reflect our truly individual traits, preferences, or tendencies because we willingly assign them that meaning. If much of con-

Timbuk2's "Build Your Own" tool for customizing a messenger bag. Size, colors, external and internal features, right- or left-handedness, and accessories are all adjustable through the online interface. (Timbuk2, 2009)



temporary production aims to respond to those consumer preferences by designing objects, services, and experiences for smaller and smaller segments—and offering avenues for "mass customization"—then it foreshadows personal production, whether by digital fabrication or some other means.

Mass customization, as a design strategy, relies on those information technologies that collect and administer massive amounts of data about people and products. Without this particular capability, finely differentiated components—whether formal or functional—and products would have little chance of being built, let alone of reaching their target users. The success of targeted merchandise and advertising makes this data-collection possible (and profitable). But in its current state, mass customization doesn't fully utilize the data collection performed on each and every consumer, nor does it substantially alter the consumer-product relationship. Currently, we can mostly make only superficial choices for product customization—recall the different available colors of a MINI Cooper—focusing on formal rather than functional options.[11] For example, we can choose color, surface materials, or sizing, but we cannot fit a tool's grip to our hand.

Fab's information technology (3D modeling, object databases, personal data collection, etc.) easily allows those functional customizations. But the "back-end" of fab plays an additional, unintended role of modifying the epistemological and ontological status of the built world as well. With digital fabrication, man-made objects exist first as data models—richly informative digital "things" that evince the general and individual characteristics of the object, materials, designers, and users.[12] Virtual objects potentially maintain their symbolic value even before fabricating their tangible counterparts; as instances of personalized data, that sign value escalates. The information technologies required for fabbing and the kind of knowledge made available to us as a result of using those tools together alter what we can know about our personal, material worlds.

Digital fabrication—as a hybrid production and information technology—suggests other changes in consumer-product relationships as well. Increasingly customized production could lead to people designing for themselves. Each person creating unique objects, suited (and known) to them alone, changes the ontological category of "product." With mass production, the most successful products are those that appeal to the broadest audiences. With fab, the most successful products might be the most specialized, but there's no way to measure that success. This specialization reconceptualizes a consumer "mass," simultaneously changing the group identity of objects and the people they target. Since products, and product categories, serve as signifiers within an economy of signs, shifting the status or value of those signs and their users fundamentally changes that symbolic economy.

The advent of digital fabrication could also influence social conditions. We can interpret its appeal as part of a growing aversion to the globalized nature of transnational capitalism's regimes of production felt by some segments of consumer society. "Buy local" campaigns, vehement backlash against opaque and dangerous production norms, and worldwide fair trade efforts, among other movements, all indicate a distrust and repugnance toward current means of production. Those in the privileged global North cannot help but become increasingly

Objects come out of a 3D printer fully operational, for example creating internal, independent ball-bearings without assembly. (Rich Lyons, 2008)

aware of the social inequities and environmental degradation that predicate their consumerism because the communication technologies that make globalized production possible and lucrative also make the resultant social and ecological injustices excruciatingly visible. Consumer capitalism has responded in a frustrating, if unsurprising, way: by introducing new products (new signs in its symbolic economy) that convey a concerned or oppositional identity or at least purport to do so.

Technologies that facilitate globalized production through their intensive data infrastructures—and make visible its harmful side effects—have altered our *personal* information landscapes as well. The satellites tracking merchandise from one side of the globe to the other also track our cell phones, laptops, vehicles—any device with which we travel. Generally, we're unaware of the "datascape" created by these movements, though we inflect it, add to it, and make use of it, intentionally or not. For the most part, these information models of our daily movements, medical histories, and buying preferences are a privacy intrusion we've mostly been happy to have; we like that our car knows where pizza restaurants or hardware stores are located; we extol the efficiencies digital records have brought to healthcare. We're happy not to enter our shipping and billing addresses one more time. For most of us, impositions by the datascape are perfectly acceptable trade-offs for extended and personalized services.[13]

As most of us become comfortable with information technology, fabbing has potential to prevail in (if not dominate) production because it fits neatly into an already data-saturated world. Other modes of production use digital information to prototype, analyze, or track products; fab uses data as a primary

component in making them. Empowered citizens of the near future won't only be producing things for themselves, but also manipulating their personal datascapes in service of their own demands and delights. They will view information—as fab does—as "raw" material to shape.

In constructing things one at a time, fabbing builds objects that are fully operational as soon as they are printed, and each object can easily be unique, or at least truly customized, to its user and situation. It's as simple to print a large teacup along with a smaller one as it is to produce two of the same size.[14] Each unique instance requires only a three-dimension digital model—models which take up less space and are infinitely more transferable and reproducible than traditional manufacturing molds and tools. But while fabbers use data as a material, they still require actual material inputs to produce physical objects. At this time they mostly print in polymers—plastics—of varying sorts and sources. Though, increasingly, fab offers products made from metals, ceramics, organic compounds, or combinations of these materials.[15]

The transportability and reproducibility without generation-loss of digital models begins to relocate production; fab's potential to offer customized, clean, and on-demand production invites its localization. The technology's evangelists predict that fabbers will land in our homes and offices—literally on our desktops.[16] Neighborhood service bureaus—"fab labs"—seem more likely, at least in the near term. Fab labs could function like a Kinko's that prints objects instead of images or documents. A variety of fabbers would cover all range of production: from replacement cell phone parts (plug in and let the computer diagnose and deliver) to full-service design and production

Shapeways.com offers simple online tools for uploading and ordering three-dimensional objects. Though these mostly tend toward toy-like or proof-of-concept forms, the company marks the beginning of publicly available fabbing service bureaus. (Shapeways, 2009)

of more complex products like furniture. Though far from perfect—as anyone who has visited a Kinko's recently can attest—local fab service bureaus could go a long way to addressing some of the major concerns with globalized mass production.[17]

Still, the fab lab projection lacks a major element: it doesn't tell us how localized production—the process of customization—might actually occur. We easily recognize how fab's inputs of digital product models come to exist, and that they are so compact that each person could reasonably maintain a whole library of personalized models. But without constructing them from scratch, how do we personalize the generic? A second set of data must exist describing individual physical, habitual, and environmental attributes and preferences. For example, I would need the dimensions of my hand, the climate I live in, my personal patterns of circulation, and my material preferences, all in communicable form, to fab personalized gloves.

This personal data profile ought to record the past, document the present, and project the future activities and localities of a singular person. Fortunately, most people likely share many of the characteristics—physiological, habitual, or preferential—with the people around them. Our teeth resemble those of our siblings, and we share the same basic work and sleep schedule as local strangers in a similar profession. Data profiles, especially their projective components, would come to reflect our social relations and wouldn't require intensive surveillance. More and more, surveillance requires no visible presence or physical contact; the devices we use every day and the environments we travel within perform that sensing and collection unobtrusively.

The status of products as both generalized objects and instances of personalized data could redefine, or at least challenge, the current norms of mass production.[18] It could shift our production away from distant megafactories toward a micro, localized form. Fabbed products exist in multiple realms: physical, digital, and symbolic things. We can "know" a single object in at least two ways, haptic and virtual. Virtual things represent an overlap of the larger datascape with our own personal traits and desires (as recorded in our data profiles). This overlap condition, although intrinsic to the creation of any object, is more pronounced in fabbed things than in traditionally manufactured products. In some sense, a fabbed object has more in common with hand-made bespoke items even though fab production distances it in time and in the manner it is made from those bespoke objects.

The convergence of generic product data and personal profile shifts the status of both *consumer* and *product*, establishing a new consumer-product relationship. Products begin to exist as part of generalized series and simultaneously as personalized instances. Not since the arts and crafts movement and the guild era has a mode of production offered us the opportunity to exercise such agency to influence the production of our stuff. And, like the arts and crafts movement, the rhetoric around fab promises social equality through production without offering much practical detail as to how the vast majority of people might achieve it.

We might speculate about the ways fab could alter our social relations along with this ontological shift in the status of the built world; with digital fabrication, consumers adopt a role in the creation of their belongings, and not just because they get to press *print*. Individual consumers—the data that describes them—become one of the inputs in production. Products come

into existence as a hybrid between person and product. Human experience and physicality, codified in a personal data profile, merges with object-related data to form each thing. Through this process people grasp what could be called "generative potential."

However, to truly exercise that potential, to act with agency in the built world, requires the ability to actively control and shape that personal data. Shaping one's data profile, directly influencing the production of objects made from that data, qualifies as a kind of literacy and privilege. It seems likely that this literacy will develop in a manner akin to what we've observed in the spread of digital image-making and communication tools. What began as privileged media for the technical elite—digital photography and cell phones, for example—have become commonplace, and more importantly, user-friendly tools.[19] But imaging and communication tools like mobile telephony did not become simple and easy-to-use on their own. Technology engineers and designers worked for years developing the interactions and functionalities that make these products useful and usable (and that work continues). As they have become familiar with these design conventions, users have learned to acclimate to and accept the conceptual models of information, space, and time that these technologies rely on.

Digital fabrication presents production as a mode of empowerment, including consumers in design and production, and rendering them a user-producer. But what does the recasting of consumers do to designers? How will design practice respond to this change? Fab seems to offer a real alternative to our current reliance on globalized manufacturing. It suggests that products (and therefore manufacturing, or at least fabrication) could have a flexible response to human experience. The idea of personal fabrication allows users to develop a product to fit a need or desire that actually arises, rather than one created for them by the engines of mass production and mass marketing.

Contemporary industrial design practice has reached a crisis point, though that's not abundantly clear to many involved. More degree programs in product and industrial design exist than ever before in history (not surprising given the staggering volume and variety of goods manufactured). Moreover, a few notable designers have garnered celebrity status. Design stars—Karim Rashid, Yves Béhar, Michael Graves, to name a few—have become familiar brands thanks to a culture in which individuals are obsessed with distinguishing themselves through the provenance of consumer goods. These personalities, like all celebrities, no longer represent people at all, merely brands distinguishing one plastic trash bin from another.

Name-recognition and widespread professional and academic credibility could mean that industrial design has reached its pinnacle. But these highlights coincide with growing understanding within the profession of the ecological (and social) crisis caused by unfettered consumerism. Product design remains inextricably linked with the progression of consumer capitalism. In my view, the design community has come to realize that it must fully reconfigure its role in society if it (and all of humanity) is to survive. Though the man-made ecological crisis has already claimed lives and territory, threatening our future, design has barely begun to respond. The most visible efforts fall under the rubric of "socially-conscious" design—rustic products for disempowered populations. Designers, particularly industrial designers, have not yet found a true alternative

to the consumer-product model on which the profession predicates itself.

A new design for interacting with material culture is required —this is what fabbing offers. Personal fabrication does not mark the end of industrial design as a professional pursuit, but it might be a chance to unravel our singular allegiance to consumer capitalism. This demands shifting focus away from the object, whatever it may be: car, toilet paper roll, or diamond tiara. Fab insists that we re-envision product design as an interaction, a translation of haptic, material, and mechanical intelligence into tools non-professionals can productively manipulate.

Personal fabrication by user-producers requires building a new conceptual model of the design process and designer. To accomplish this requires an extension beyond the re-centering of contemporary design processes onto ever-smaller target audiences, eventually reaching individuals. This vision demands more than increasingly precise design personas made feasible by immensely powerful processors and enormous datasets. Here begins the real predictive technological futurism. Futurist rhetoric offers more than points of reference or convenient ways to communicate an advancing technological paradigm; it can serve as a strategy for designing new product-consumer relationships.

Designers will shape the way personal and object data converge within a new regime of production, and how we internalize that convergence. The way a new class of fabbed objects will actually be generated—what steps go into their making, what questions we pose before and during their production, and what happens afterward—will shape a new designer-product relationship. Because fab, particularly the way it handles information about the built world, changes products, product designers will also change. They must become as data fluent as their tools and products are data saturated.

Fab's adoption will mean that designers are less likely to formally author particular objects, either as bespoke items or mass produced products available any and everywhere.[20] Instead, they will give form to a seed object that will merge with the personal data of its future users. Designers will shape the ways that personalized information affects those generic seed objects. Production will increasingly call on designers to translate their haptic, material, and ergonomic intelligence into functions and processes instead of discrete objects or product attributes. As a result, the profession will likely adopt traits and processes from interaction design.[21] Most critically, product designers must project their designs into an unstable future as part of their design process.

Product designers of the near future may not much resemble their immediate predecessors (at least not the most famous ones whose work we recognize). Individual authorial vision will take a backseat to the ability to imagine and shape cohesive series of objects even when their final form is not entirely up to the designer. To some designers this will undoubtedly feel like a loss of creativity, agency, and control. But I believe it actually empowers them even as it shifts substantial components of their practice to users of their designs. The fab-enabled production regime offers to put designers in closer contact with their audience of users (though digitally mediated much of the time). By localizing major components of design practice, fab might allow product designers to abandon their role as stylists for global capital.

The localization of design actions—performed by both professional designers and by users themselves—cannot help but expand the design profession. I believe we are likely to see continued growth, not attrition, of the profession as the world of products becomes more complicated. With this growth, we may also see continued specialization with designers focused on *very* particular populations and product categories.

The recent history of graphic design, particularly the emergence of "desktop publishing" and the internet, corroborates this prediction of expansion and specialization. Rather than ruining the profession, these two developments have expanded the field. Localization of the means of communication resulted in a proliferation of graphic forms and areas of expertise, not a narrowing. However, the new cadre of localized designers is, in many ways, significantly less "professional." They no longer work primarily for large media interests (even as those conglomerates have become more concentrated and powerful) or elite consultancies. Graphic, communication, and web designers have become in-house staff for many kinds (and sizes) of businesses and organizations; scores of designers work as independent studios, with just a desk or a briefcase of equipment. Moving digital modeling and fabrication onto personal computers and into neighborhood service bureaus offers a similar localization and specialization for product design practice.

A move toward localization predicated on growing access to the means of production—as seen with desktop publishing and the future projected by fabbing—has done more than alter the design professions. It has laid the groundwork for a significant and effective challenge to the concentration of media and production interests that has characterized the last few decades.

As such, it could pose a real threat to the status quo of late capitalist means of production. Neither fab nor its utopian longings are likely to undermine it entirely, but the model of production they propose seems to have the potential to shift the balance of powers and perceptions of our own identities, material culture, and generative potential.

Notes

1 This ad, proof-of-concept videos, and fantasies about of the future of making are widely available on YouTube. They serve as popular—often user-generated—propaganda.

2 Latour, B. 1994. "Pragmatogonies: A Mythical Account of How Humans and Nonhumans Swap Properties". *American Behavioral Scientist*. 37 (6): 794.

3 Fab has a peculiar allegiance to the *Star Trek* replicator, discussed in detail in my full thesis, *The Future is Fabulous: A Critical Anthropology of Fabbing*, 2009.

4 It should come as no surprise that the engineers and inventors developing fab would gravitate to narratives that lionize their particular set of interests and talents. These visions tend to depict technocratic social utopias where all individuals have the intelligence, physical capability, and socio-economic status to make anything they might need or want.

5 These technologies did not undermine the existence of professional graphic design practice, as some predicted they would, though they did prompt significant shifts in the ways that practice conducted itself. I discuss this further below.

6 Sterling, Bruce. 2002. *Tomorrow Now: Envisioning the Next Fifty Years*. New York: Random House, 76.

7 These technologies couple with the emergence of consumer classes in the developing world that mirror the post-World War II consumer boom in the global North.

8 Radio-frequency identification chips are tiny radio transmitters embedded within products and packaging that facilitate inventory, identification, and tracking of objects without physical counting. The chips are read by proximity scan, and they can transmit significant quantities of data instantly. RFIDs can even be read without the knowledge of those in possession of the object.

9 Claudia Donà, "'Invisible Design" in *Design After Modernism: Beyond the*

Object, ed. John Thackara (New York, N.Y.: Thames and Hudson, 1998), 152

10 Csikszentmihalyi, Mihaly, and Eugene Rochberg-Halton. 1981. *The Meaning of Things: Domestic Symbols and the Self*. Cambridge [Eng.]: Cambridge University Press. 93.

11 True manufactured customization does thrive at the most expensive extreme; for roughly $250 million you can have a Boeing 747 made to your custom specifications; in fact, there is no such thing as a standardized—non-custom—747 airliner.

12 This is not unique to digital things; physical objects communicate the same information. However, physical objects don't necessarily provide the means to interpret that information in the same integrated way modeling environments do.

13 Widespread use of the services and experiences that rely on surveillance and data-collection—GPS guidance, digital health records, even the "auto-filling" of online transaction, just to name a few—suggests that the public is not really averse to being watched and tracked. We opt to have personal data collected and stored by government agencies and corporations because they offer us cost and effort-saving tools; we willingly make the trade.

14 Scale is only one of the most basic functional customizations three-dimensional printing can offer. More complex adaptations, such as differently proportioned components or material variations, begin to hint at the potential of fabbed objects to suit individualized needs.

15 Many of these polymers are recyclable. Fab inventor-evangelist Adrian Bowyer suggests that every fabber ought to contain a recycler component that can turn old fabbed products into raw materials for new ones. Unfortunately, compound materials are inherently more difficult to break down and recycle.

16 Gershenfeld, Neil A. 2005. *Fab: the coming revolution on your desktop—from personal computers to personal fabrication*. New York: Basic Books. And, Bowyer, Adrian, "The Self-Replicating Rapid Prototyper—Manufacturing for the Masses" http://reprap.org/bin/view/Main/PhilosophyPage. Originally presented as the keynote address at the Seventh National Conference on Rapid Design, Prototyping & Manufactring at the Centre for Rapid Design and Manufacture in High Wycombe in June 2006.

17 Following this project to its logical extremities, we would assume that the fabbers themselves and input materials would be produced off-site. However, even in that scenario the benefits reaped by on-demand printing (such as supporting local economies and reducing inventory costs) would be gained. Fab's biggest cheerleaders, Adrian Bowyer for example, suggest that fabbers might actually be capable of reproducing themselves where needed and that they could run entirely on recycled fabbed objects.

18 We might view the alteration, embellishment, and after-market customization of consumer products in a similar light, though the information contained in these modifications is difficult, if not impossible, to extract from the physical forms.

19 As of the end of 2007, there were 3.1 billion mobile phone users worldwide and 4.5 billion are forecasted by 2012. (Market Intelligence Center cited by Reuters: http://www.reuters.com/article/technologyNews/idUSL2917209520071129 among others.) A technology platform used by roughly half the world's population demands that we reconsider classist critiques that technology advancements only reach the wealthy global north. People without well-established technological infrastructures sometimes "leapfrog" tech advancements; adopting mobile phones before landlines could ever be installed. We could imagine a similar leap with digital fabrication.

20 This recalls the shift from print to web design. Graphic designers had to relinquish control over the exact look of the page; their designs were always interpreted through the user-specified settings of the reader's computer and browser software.

21 We have already begun to witness this change. As products become computerized and informatically-enabled, product designers have had to let go of the assumption that they know how someone will interact with their work. There are simply too many possibilities to envision all of them.