Contributors

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Tom Fisher is Professor of Art and Design at Nottingham Trent University, United Kingdom. A graduate in Fine Art, he has worked as a designer and maker of furniture, and wrote his PhD in the Sociology Department at the University of York, concentrating on everyday experiences of plastic materials. His current research focuses on the materiality of human-object relationships and their implications for sustainability. In this, he draws on his background as a maker and on perspectives from the sociology of consumption. He recently published *Designing for Re-Use: The Life of Consumer Packaging* (Earthscan, 2009), which reports on ethnographic work in the United Kingdom that uncovered the range of ways in which people reuse packaging. The book presents a number of ways of thinking about the phenomenon of packaging reuse, and indicates the role that design can play in promoting it.

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Jody A. Roberts is the Director of the Center for Contemporary History and Policy at the Chemical Heritage Foundation in Philadelphia, PA, United States. Roberts's work explores the intersections of emerging molecular sciences and public policy and the ways in which tensions brought about between the two get resolved. He received advanced degrees in science and technology studies from Virginia Tech, where he cultivated an interest in the practice of the molecular sciences and the ways in which they are shaped by internal architecture and design (e.g. technologies of the laboratory) and the politics of the broader world (e.g. chemical regulations). He also holds a Bachelor of Science degree in chemistry from Saint Vincent College. Roberts held fellowships at CHF before joining the staff of the Center for Contemporary History and Policy in 2007. He lectures in the History and Sociology of Science Department at the University of Pennsylvania and the Centre for Science, Technology, and Society at Drexel University. He is also a Senior Fellow in the Environmental Leadership Program.

Shige Takada received his PhD from Tokyo Metropolitan University in 1989. His speciality is trace analysis of organic micropollutants. The target compounds include persistent organic pollutants (POPs; e.g. PCBs, DDTs, PBDEs, PAHs), endocrine-disrupting chemicals (e.g. nonylphenol, bisphenol A), pharmaceuticals, as well as anthropogenic molecular markers. His research field encompasses Tokyo Bay and its vicinities, to South-East Asia, to Africa. In 2005, Shige Takada started International Pellet Watch, the global monitoring of POPs by using beached plastic resin pellets (www.pelletwatch.org). He has been working with ~50 non-governmental organizations and individuals who have concerns about marine plastics pollution. Shige Takada (Hideshige Takada) has authored more than 100 peer-reviewed papers in international journals and has attended more than 20 invited conferences.

Richard C. Thompson is Professor of Marine Biology at Plymouth University, United Kingdom. He is a marine biologist specializing in the ecology of shallow-water habitats. He has a first-class degree in Marine Biology from the University of Newcastle upon Tyne and a PhD from the University of Liverpool. He moved to Plymouth University in 2001, where he helps run the BSc Marine Biology degree programme and lectures in marine ecology. Much of his work over the last decade has focused on marine debris. In 2004, his group reported on the presence of microplastics in the environment in the journal *Science*. Subsequent research examined the extent to which microplastics were retained upon ingestion by marine organisms, and the potential for microplastics to transport persistent organic pollutants to organisms. In 2007, he was invited to be lead guest editor for a 200-page volume of the *Philosophical Transactions of the Royal Society B*, focusing on plastics, the environment and human health. He is a co-author of the European Union Marine Strategy Framework Directive Task Group 10 on marine litter, and recently has prepared two reports on marine debris for the United Nations Global Environment Facility: *Marine Debris as a Global Environmental Problem: Introducing a Solutions Based Framework Focused on Plastic* (2011); and *Impacts of Marine Debris on Biodiversity: Current Status and Potential Solutions* (2012).

Andrea Westermann works in the History Department of the University of Zurich, specializing in the history of science and technology and environmental history. She wrote her first book on the history of plastics in West Germany. She is currently writing a book on knowledge validation in late nineteenth- and early twentieth-century geology. Recent publications include 'Disciplining the earth: earthquake observation in Switzerland and Germany circa 1900', in *Environment and History*, and 'Inherited territories: the Glarus Alps, knowledge validation, and the genealogical organization of nineteenth-century Swiss alpine geognosy', in *Science in Context*. She is partner investigator with Gay Hawkins on the research study, *The Skin of Commerce.*

Introduction

From materiality to plasticity

Jennifer Gabrys, Gay Hawkins and Mike Michael

Figure I.1 Academics and plastic at work

In Figure I.1, two of the editors are busily working on the introduction to this volume, moments after we had decided on how to approach it. It should be obvious that we are surrounded by plastic. There are plastic objects such as pens and computers, the plastic packaging of a water bottle and a punnet of cherries; there is plastic covering the chairs, laminating the table and encasing the printer; and there is plastic making the meeting physically feasible – plastic in the light fittings, in the carpets, in the window frames (it was a cold, dank London June day). Inevitably, there is plastic in our clothes and on our bodies. This is our first meeting together since the *Accumulation* conference, an event we had co-organized the year before that brought together a number of the authors included in this collection to examine the material force of plastic as raw material, object and process. Organizing this interdisciplinary event and collection of speakers would have been impossible without a wealth of other plastics, from the plastic in trains and airplanes to the plastic in credit cards. All this simply goes to underscore how central plastic has become to processes of contemporary sociomaterial living.

This is an easy observation to make. From the first fully *synthetic* plastic – Bakelite, developed in 1907 – to the current proliferation of polymers, we produce, consume and dispose of plastics in untold quantities. In the corresponding plethora of studies on the rise of plastic, its rapid uptake and ubiquity are regularly noted. Previous research on plastics seems to have appeared every decade or so since its widespread application within post-World War II consumer economies. As early as 1957, cultural critic and semiotician Roland Barthes wrote a classic essay on plastic, which he developed as a comment and critique of this substance as he witnessed it arrayed in a plastics exhibition in Paris. In 1986, designer Ezio Manzini published *The Material of Invention*, which emphasized the material performativity and interchangeability of plastics. In 1995, historian Jeffrey Meikle wrote a sophisticated and nuanced account of how plastics had influenced American culture. More recently, an increasing number of pop-culture and pop-science commentaries on plastics are emerging that chart the toxicity, intractability and spread of plastics. Susan Freinkel's (2011) *Plastic: A Toxic Love Story* exemplifies this trend by mixing due recognition of the benefits and necessity of plastic with a consumer guide to its environmental and noxious horrors. In different ways, these texts explore how *things* have become decidedly synthetic to the point where plastic now appears as the archetypal material of invention, mass consumption and ecological contamination.

Beyond this opening vignette, and gesturing toward post-war and recent literature, a host of other plastics-related issues are waiting to be excavated. The purpose of this collection is to explore the vitality, complexity and irony of plastics, and to examine a range of plastics-related issues that cut across art and design practices, humanities, natural sciences, politics and the social sciences. We are not seeking to establish a general narrative about the evolution of plastics. Nor do we wish to frame plastic as emblematic of social and environmental change. Rather, the aim is to capture the multiplicity and complexity of plastic by engaging with its processual materialities, or *plasticity.* As we suggest here, plasticity extends not just to the multiple forms and uses of plastics, but also includes the ways in which plastics are integral to contemporary material processes, and even give rise to events such as environmental or bodily accumulation that present unexpected and often undesirable modes of material transformation.

Accumulation engages with the particularity of plastics in order to draw out these aspects and implications of plasticity. The collection presents a series of chapters that address plastic in its concrete manifestations, including PET (polyethylene terephthalate) water bottles, credit cards, degrading and biodegradable plastics, everyday litter, marine debris, rapid prototyping, mobile phones, oil and oil transportation. These examples provide richly detailed accounts of the ways in which plastic is woven into and enacted through social, cultural, political, technoscientific, ecological and economic practices. In all of these accounts, plastics are part of transformative material engagements. What emerges through these empirical object studies is how plasticity provides particular ways of thinking about and advancing understandings of materiality *as process*.

Both the fact that plastic has become an object of variegated analysis more generally, and that this collection has become possible to assemble, deserve comment. On the one hand, we can put this down to a number of developments in the social sciences – for instance, the recent 'turn to the object' exemplified in such perspectives as material culture studies, science and technology studies (STS), or recent versions of the sociology of everyday life. These approaches have been particularly useful in helping us to engage with plastic materials and objects, not least by rendering them 'seeable' and lifting them from their fog of familiarity or background passivity, thereby making them interestingly and productively unfamiliar. Plastic complicates this turn, however, for it is not just the world of objects that is defamiliarized, but also the material properties that constitute those objects. Plastic draws attention to the materiality of objects *and* the shifting properties of those materials.

Plastics have also become defamiliarized by making their presence felt, by becoming a very insistent matter of concern, where discarded plastics and a whole range of plasticizers added to polymers increasingly are understood to induce harmful effects on bodies and environments. More than any other material, plastic has become emblematic of economies of abundance *and* ecological destruction. If the post-war 'Plastic Age' was cleaner and brighter than all that preceded it, this boosterism has now become intertwined with significant anxiety as the burden of accumulating plastic waste registers in environments and bodies. The indeterminate and harmful materialities of plastic are now surfacing and demanding urgent attention. Over the last 10 years, there has been increasing public controversy about the endocrine-disrupting effects of plastic, about the emergence of massive plastic gyres in several oceans, and about the ethical and environmental impacts of the global spread of disposable plastic cultures. Because they are made in part from petroleum, plastics have become a marker of dwindling natural resources and accumulating synthetic pollution, with their limited degradability signalling indefinite processes of environmental degradation. Plastics simply refuse to go away, and their material recalcitrance forces us to acknowledge the ways in which plastics persist long after their use value is exhausted (Gabrys 2011).

This edited collection then engages with these multiple qualities of plastic to think through questions related to emerging areas of materialities research. There are a growing number of studies on the ways in which materials matter and inform political engagements (Bennett 2010; Braun and Whatmore 2010;

Hawkins 2010). We situate this volume in conversation with these studies, and through these investigations into plastics consider how plasticity distinctly informs our ways of encountering and mobilizing material research. Among the questions to be addressed in this collection, we ask how it may be possible to engage with the processual materiality or plasticity of plastic without fixing it as an object of study or illustrative case. In the various chapters presented here, we ask how the recalcitrance of plastic, its durability and persistence, might reveal the material and relational exchanges that take place between humans and non-humans. We also consider further how recognition of the material force of plastics prompts new forms of politics, environmental responsibility and citizenship. A key concern running through these questions is how we might begin to develop an analytics attentive to plastics in order to provoke invention and invite new forms of material thinking. This, as we suggest in this introduction and throughout this collection, involves attending to the *material politics* that emerge through the processual materialities of plastics.

Material politics and the event of plastics

What stands out from the photograph with which we began this introduction is the sheer number of plastic objects and materials that surround the 'human subjects'. There are now over 10,000 types of plastic polymers in use, and worldwide consumption of plastic has gone from barely measurable quantities in 1940 to 260 million tons per annum today (Thompson *et al.* 2009). As such, we might ask how we should think about the multiplicity of plastics that make themselves present in the event of this meeting and beyond. Is there a plurality of different plastics and their related objects – some of which feature overtly or covertly in this scene? Or is there a singular family of plastics the common, unique and abiding property of which is the capacity to take on multiple forms? This raises the issue of the ontological status of plastic. Is it something that has certain intrinsic properties or recalcitrance, or does plastic emerge from the multiple relations in which it is embroiled: in chemistry, in industry, in processes of marketing and consumption, in plastics waste management? Or is this dichotomy itself less than useful? Put another way, can we move beyond this staging of the issues by, rather than *applying* this dichotomy (and its problematization) to plastic, thinking it *through* the specificities of plastics. In this way, the focus shifts to developing an empirical ontology of how multiple plastic realities are enacted and their effects.

What is plastic doing in the world? What might it do? Questions about the concrete effects of specific manifestations of plastics quickly lead to political entanglements, but the political questions that emerge in this study do not just stem from a human assessment of 'bad impacts'. Instead, we suggest that plastics generate a series of causes or political reverberations that genuinely constitute modes of material politics, which emerge from the concrete events of plastics in the world. The material politics of plastics can then be seen as emergent and contingent, where plastics set in motion relations between things that become sites of responsibility and effect. From this perspective, a material politics informed by plastics is less oriented toward asserting that materials are always already political. Instead, in this collective study on plastics, we variously focus on when and how plastics as materials *become* political. Through which material processes and entanglements do plastics 'force thought' and give shape to political concerns (Stengers 2010)?

Plastics, as it turns out, may teach us something about politics. The mutability of this material generates distinct political encounters and events. Rather than assume the prior political status of materials, we then ask in relation to plastics: in what ways are these materials political, and how do political moments and matters of concern emerge in relation to these materials? This point is important, since from this perspective we begin to think about the new relationalities that plastic is generating, and how these relationalities become sites of responsibility. Rather than argue for the simple elimination of plastics, we suggest that the material politics of plastics require that we attend to these unfolding relationalities and responsibilities in order to ask: to which material and political futures are we committing ourselves, and in what ways might an inattention to the material politics of plastic foreclose opportunities for inventing different material futures?

This collection seeks to offer insight into the ways that a 'politics of plastics' must deal with both its specific manifestation in particular artefacts and events, and its complex dispersed heterogeneity. This approach challenges the abstraction and universalization of plastic as the passive object of political deliberations or a problematic material demanding human management. Instead, the focus is on how plastics rework material relations within and through synthetic and dynamic processes. Plastics, in this sense, can refresh thinking on materiality by forcing an attention to material processes within which we are specifically situated, but which are not bounded objects of study.

As the plastics photograph and this discussion suggest, the *event* of plastics is a key way in which the materiality of plastics is encountered and understood. Even to talk about the photograph that frames this introduction as a representation of plastics is to neglect the fact that it is *doing* something. Clearly, by foregrounding certain elements of plastic and the academic approach to the study of plastic while downplaying others, the photo is setting up – performing, enacting – a very particular vision of plastic and academic work. This vision can have effects – at the very least, to persuade readers that they should subscribe to that vision (and change their practice accordingly). However, the performative dimension of plastic resides not simply in our enactment of it through a photograph; plastic is enacted more broadly through the complex relations that comprise it.

Framing the photograph in a different way, we can see before us an event in which a series of elements come together – from the sub-atomic to the social-relational – to render plastic in a range of ways. We have touched on some of these already: plastic tools, materials, components, markers of resource depletion and environmental degradation, objects of academic study. However, out of the event emerge not only the non-human elements, but also the human. In other words, we also see the array of plastic partially enacting the academics: in the specificity of the event (we might also call this an assemblage), these plastics (along with myriad other elements) enable particular sorts of humans to emerge.

It will not have escaped notice that to talk about enactment, emergence and indeed affect is also tacitly to raise the matter of causality. Causality underpins much of the assessment of the environmental impact of plastics, but this is not necessarily a linear causality. Often the impact of plastics operates within complex systems in which it is not at all clear what the outcomes will be. That is to say, in this collection of plastics studies we attend to the 'emergent causality' of plastics (Bennett 2010), and how this is at play in both the production of environmental impacts and the sociomaterial enactments of humans – and indeed, more-than-humans.

This last phrase – the more-than-human – also throws into relief the fact that our initial reading of the photograph may be disingenuous on another level. We have been seeing plastics and humans separately, as distinct entities interacting with one another. Yet this opening commentary has in many ways focused mainly on their intra-actions: their mutual emergence, their becoming-with. Or, to frame it another way – which is somewhat less concerned with the standard units of human and non-human – what we can also see are concrescences (here drawing on Whitehead 1929), at least minimally composed of combinations of academic and computer, or academic and pen. As such, when we turn to the analysis of emergent causality or enactment, we also need to ask about what might be the most fruitful units of analysis. At which level can plastic objects and events be identified, and with which sorts of entanglements are these objects and events further connected?

Material thinking as inventive problem making

Finally, and relatedly, the photograph and the taking of the photograph are, like plastic, nothing if not oriented to the future. The photograph points to the future promise of a book, just as plastic is wrapped up in a panoply of expectations, hopes, fears and hypes of plastic. However, these promissory accounts that accompany plastics are but another element in the event in which plastics emerge – they are performative of what plastic might be, and how plastic might affect the world – but there is no guarantee of realizing that particular promise, or any particular future. The event, including the event of plastic, is chronically open. This begs the question of not just what our unit of analysis should be, but also when and how it must incorporate this openness. More provocatively, what does analysis mean when our object is fundamentally in-process? Is the function of this volume to provide a solution to the problem of plastic's processuality? Somehow to pin it down? Or is it to pose the problem better, more inventively?

Such 'inventive problem making' (Fraser 2010; Michael 2012) is a strategy we have developed by bringing together diverse perspectives on plastics. In editing this volume, we have gathered together an interdisciplinary range of engagements with plastics. The chapters collected here draw on very different epistemic traditions, from cultural studies to design and the sociology of science and technology, as well as history, geography, economic sociology, organic biochemistry, environmental science and environmental politics. The immediate issue that might arise would concern the 'management' of such interdisciplinarity, but we might see such disciplinary interactions as an opportunity for producing new 'objects of knowledge' by virtue of the reconfigured relations brought together through such interactions. Here, what counts as 'object' and 'knowledge' can shift dramatically.

In this sense, we could see the interplay of two classical epistemological directions, respectively and crudely, from knowledge to the material, and from the material to knowledge. Another way of saying this would be that changes in knowledge reshape our engagement with the material world, at the same time as the material world affects our knowledge and knowledgeability. This dynamic is at the heart of 'material thinking' (Carter 2004; Thrift 2006). One of the objectives of this book is to trace how distinct types of material thinking emerge and might yet be invented in relation to the specificities of plastics. Such a move in part takes up Stengers's interest in engaging non-humans 'as causes for thinking', which, because they 'force' thought, cannot be taken for granted within a standard 'state of affairs', but must be encountered as shifting connections and new, if problematic, sites of collective becoming (Stengers 2010: 14–17).

'Ecologies of practice' across humans and non-humans, as well as disciplines, is a term that Stengers (2005) coins to describe these moments when new connections, obligations and possible modes of speculation emerge. We take up such an experiment in ecologies of practice, working not just across carbon-based humans and polymer-based non-humans and the multiple new arrangements that emerge through these intersections, but also drawing on an interdisciplinary range of approaches to plastics. Interdisciplinarity is a process in which often mutually incompatible framings are brought together, but do not always easily align.

New plastic objects and ways of encountering plastics emerge through these reconfigured relations, and participants may even change in the process of negotiating what counts as thinking with plastics. These changes are not simply cognitive or epistemic, or even ethical – they are also affective. That is to say, in interdisciplinary discussions of plastic, there is a certain human plasticity that is exercised – an affective accommodation of the other that allows for initial toleration if not always understanding, and common practical orientation if not always mutual comprehension. The point is that it will also be necessary to address how the juxtaposition of approaches that characterize this volume yields partial connections that can resource a complex reimagining (that operates on epistemic and affective registers) of how plastic can be known and, indeed, enacted.

Accumulation brings divergent perspectives into a timely dialogue around and through the multifarious materialities and events that comprise plastics. Our inventive approach to the complex material issues of plastics is to work from within the concrete events and relations that specific types of plastics enable or sustain. Through a series of themed sections on Plastic Materialities, Plastic Economies, Plastic Bodies and New Articulations of plastic, specific aspects of plastic in action are examined in the chapters that follow. These themes are both conceptual in the sense that they frame how we approach plastic and also ontological in the sense that they signal the empirical unfolding of plastics in the world. To talk of 'materialities' is to acknowledge the stuff of plastic, the physical properties of a substance and also the issue of materiality as a key focus of recent social theory. To talk of 'economies' is to recognize plastic as a locus of value both as a global industry and a specific market device. In the work of everything from packaging to the credit card, plastic co-articulates economic actions; it is both a medium of business and a material actant. To talk of 'bodies' is to focus on the ways in which we are entangled with plastic, the multiple interminglings in which humans (and non-humans) find themselves becoming with plastic, whether they like it or not. To talk of 'new articulations' is to wrestle with plastic as a material that forces thought. The problematic ontologies and matters of concern that emerge with plastics become manifest in particular artefacts and events from oil pipeline protests to ocean gyres. In this way, plastic is articulated as complex dispersed heterogeneity, not simply as bad stuff to be eliminated or avoided but as a material with the capacity, in certain settings and events, to *provoke* political actions.

Plastic materialities

What is plastic if not material? Despite all the fascination with plastic objects and their ubiquity, what about the material locked up in these things? How can we investigate the relationship between the properties of plastic as a chemical-material substance and all the things and products it becomes? This interaction between physical properties and the seemingly endless capacity of the material to be materialized is the focus in Part I of this collection. Taking up Manuel DeLanda's imperative to study the behaviour of matter in its full complexity, our aim is to understand the processes whereby plastic emerges as a distinct material and the ways in which its material properties – expected and unexpected – emerge and are enacted in objects. This is much more than an historical investigation or a venture into chemistry or materials science. As DeLanda (2005) argues, the behaviour of materials is as much a philosophical issue as an empirical one. The close observation of materials and direct interaction with their properties was the basis of the earliest philosophies of matter. Many of these early practices of material thinking explored the variability and behaviour of materials; they were sensual and metaphysical as well as empirical. This diversity was lost with the rise of specialisms and the desire to identify essential and fixed properties in materials. The rise of chemistry was symptomatic of this shift, signalling 'the complete concentration of analysis at the levels of molecules [and] an almost total disregard for higher levels of aggregation in solids' (DeLanda 2005: 2).

However, it couldn't last. As Bernadette Bensaude Vincent shows in her opening chapter, 'plastics' challenged many of the conventions of chemistry. For it was what they could do – the multiplicity of arrangements of molecules and forms that emerged – that defined them. Unlike glass or wood, this material was referred to by its properties, by its capacity for change and proliferating uses. In this way, 'plastic' and 'plasticity' were as much cultural classifications as technical ones, but these entanglements across material capacity, technical understanding and cultural uses were shifting and uneven. Initially, as Bensaude Vincent shows, this very changeability was regarded with disdain, as a sign of inferiority and cheap substitution. Plasticity was a mark of the inauthentic. However, as the post-war Plastic Age escalated, these very properties became markers of positive value. Plasticity was an indicator of 'protean adaptability' and mass accessibility; it was the material that democratized consumption. This cultural shift reflected the dramatic expansion of uses and applications as the performance of plastic was enhanced. The development of thermosetting polymers foregrounded the philosophical complexity of plastic – namely, the way in which, through processes of synthesis and shaping, matter and form emerge simultaneously.

If Bensaude Vincent documents the plasticity of plastic, Mike Michael draws attention to the limits of such plasticity – that is, through the laboratory and factory processes where plasticity comes to be realized. Plasticity thus belongs to the sphere of production – or rather, it has until very recently. With the introduction of home 3D printers, it would appear that the plasticity of production now extends into the domestic sphere, and, with this redistribution of plastic's plasticity, anyone can produce anything at any time. Michael traces how these abstract claims for the 'democratization of production' of plastic objects are rendered, and the ways in which they are intertwined with reconfigurations and retrenchments of space (domestic, industrial, environmental), human bodies and minds (manual and ICT skills) and the future (utopian, apocalyptic). In other words, domestic 3D printers mediate a range of plastic's emergent properties that are complexly sociomaterial, spatiotemporal and actual-virtual.

Plastic economies

In Part II of this collection, we investigate what plastic does in terms of generating economic value. What is the efficacy of plastic in processes of economic accumulation? How can we think about plastic as an economic agent? Here, the focus is on plastic as diverse industries *and* as distinct market devices. Our interest is in understanding the evolution of the plastics and petrochemical industries in the twentieth century, and to examine their interrelationships with governments, markets, consumers and the environment. We also investigate how particular plastic artefacts become central to the organization of exchange, practices of value and markets. How would the accumulation of surplus value happen without the ubiquitous credit card, or the retail packaging that makes commodities and consumption fluid and mobile?

In Chapter 3, Gay Hawkins explores the rise of polyethylene terephthalate, or PET as it is commonly known. Her goal is to understand how this distinct plastic, which most often takes the form of disposable single-use bottles, became 'economically informed' – that is, how it acquired the capacity to articulate new economic actions in the beverages industry. Central to her analysis is a concern with the nature of disposability. How did plastic come to acquire the character of a throw-away or single-use material? What economy of qualities was developed to enact a temporality of transience, and how did this generate troubling shadow realities such as massive increases in plastics waste? Hawkins uses a topological approach to pursue these questions. She traces how the PET bottle can be considered a conduit of topological relations that connects plastics waste with plastics production and consumption. In her analysis, the bottle is a medium by which the multiple enactments of disposability become co-present and related, showing how the ever-growing flow of plastic moves in chaotic and multiple directions. PET bottles are *made to be wasted* and their anticipated future is inscribed in their multiple presents.

If Hawkins emphasizes the role of PET in modes of disposability, Andrea Westermann focuses on the capacities of vinyl in advancing consumer democracy in West Germany from the 1930s onwards. Vinyl was a key ersatz material that enabled a proliferation of consumer goods (and wartime materials) that at once advanced German industry and contributed to individual prosperity. Westermann emphasizes the extent to which vinyl facilitated a version of consumer democracy based on consumer citizens. Vinyl effectively became a material-political medium that generated and reinforced the possibilities for individual choice and mass consumption. However, vinyl has not been without its problems, and Westermann charts how consumer citizens became citizen activists when confronted with increasing evidence of the toxicity of vinyl.

The final chapter in this section focuses on that quintessential plastic object of economic exchange: the credit card. Joe Deville charts the rise of the credit card, and maps the practices and campaigns whereby credit cards became more prevalent as a medium of exchange, and indeed enabled more plastic or fluid modes of credit and consumption. Deville considers the extent to which the plasticity of the credit card is a key part of its circulation, and extends this analysis to contemporary examples of debt and default. In these cases, the material presence of the credit card may become a site where the promise of credit is revoked through the demand that credit cards be cut up or returned, or it may become a site of protest, where credit card users refuse to comply with the material demands of credit card companies. The plasticity of credit cards, Deville suggests, is not incidental to the functioning of credit, but becomes a feature that unfolds in multiple and at times contradictory ways.

Plastic bodies

While plastic economies in many ways demonstrate the ways in which plastics have become more pervasive and central to the circulation of value, plastic bodies grapple with the ongoing effects of living in increasingly plasticized environments, as explored in Part III. Flesh and environments alike are now being reconstituted through the lingering and residual effects of plastics, but many of these effects are relatively new phenomena of study, with endocrine disruption and the concentration of persistent organic pollutants (POPs) now becoming topics of more thorough-going concern and research. Our daily and bodily exposure to plastics forms even before they circulate as residual and wasted matter in environments, and may settle at the level of habits and affective attachments as much as bodily incorporations. As Tom Fisher documents in his design-based discussion on plastic surfaces and mobile phones, the tactile engagements with touch-screen surfaces are a critical part of the processes through which we engage with mobile phones, and eventually disengage when these plastic objects begin to show signs of wear. The proximity of mobile phones and touch screens to bodies, Fisher finds, gives rise to distinct practices and material evaluations of plastics. The process of sustaining flawless plastics and disposing of them when degraded, he argues, can be highly influenced by how our physical interaction with devices unfolds through affective modes of embodiment.

The intimate and persistent ways in which we encounter plastics begin even before birth, as Jody Roberts precisely inventories in his compelling account of the delivery of his daughter, Helena, who was required to spend her first days and weeks of life in intensive care in order to receive medical attention, a process thoroughly dependent upon plastics. Roberts explores how someone who previously had counted himself a 'plastiphobe', and who had deliberately avoided the use of plastics, began to grapple with these new dependencies on plastics and all that they enabled. Drawing on a science and technology studies perspective, Roberts unflinchingly examines the ways in which we have and continue to become plastic – and the molecular, bodily and environmental plastic practices and effects with which increasingly we are entangled.

Following on from this assessment of the many ways in which we are entangled with both the seemingly indispensable and yet often harmful effects of plastics, Max Liboiron suggests that the particular behaviours of plastics and plasticizers may require that we rethink our models of pollution. Liboiron proposes a move away from an exclusively linear point-source understanding of pollution as occurring from a discrete source and moment in time, and instead suggests we reconsider the older and seemingly folkloric understanding of pollution as a miasma in order to account for the dispersed, multifarious, potentially low-level and yet persistent exposures to plastics and plasticizers in the environment. A miasma model of pollution, Liboiron suggests, may influence corresponding approaches to environmental policy and justice by focusing on environmental distributions and concentrations of harm, for instance, rather than individual exposure to individual substances.

Concluding this section on the entanglements of plastics and bodies, Richard Thompson brings a perspective from marine biology to the impacts of plastics on humans and non-humans. He draws connections across how the effects of phthalates and Bisphenol-A (BPA) on marine organisms, for instance, may also have consequences for humans. While uncertainty still persists about the effects of many plastics and plasticizers, harmful effects have been documented, which Thompson suggests require practical actions to address these plastics issues. He outlines proposed areas of intervention – including green chemistry and redesign of products – that might be seen as practices that plastics now provoke or force through their ongoing proliferation and problematic rematerialization of bodies and environments.

New articulations

In the final section of this collection, Part IV, we bring together chapters that consider the new articulations that are emerging or might emerge as speculative practices responding to the material politics of plastics. These are practices that are not necessarily oriented towards ideal solutions, but rather bring us back to the challenge articulated earlier in this introduction to think about more inventive forms of problem making. At what point do plastics become evident as material events that force thinking and spark new types of political engagement? James Marriott and Mika Minio-Paluello (members of Platform, a London-based arts, human rights and environmental justice organization) begin this section with a discussion of the prehistory of plastics in the form of petroleum and its distribution across Azerbaijan to Germany and England. Marriott and Minio-Paluello craft their discussion of the contentious material infrastructures that are essential to the substance and making of plastics by opening a plastic carton of ice cream, and then tracing the geopolitical commitments and invisible violence that have contributed to the material form and availability of this consumer good. Is it possible, these authors ask, to begin to think of consumer goods that are not reliant on oil?

Part of the process of making plastics evident as a matter of concern may involve bringing citizen scientists into the fold of environmental science in order to study the spatial variation and chemical risks associated with plastics in the environment. In his collaborative project, International Pellet Watch, Shige Takada asks volunteers to collect and return by post pellets and plastic fragments that collect on shores across the world. These microplastics are valuable geographic samples because they can be tested for concentrations of POPs. From these widely gathered and mailed-in pellets, International Pellet Watch has generated maps that document the spread and concentration of plastics through seas worldwide. Bringing plastics and practices of studying plastics to wider publics is a process whereby plastics may be seen to be contributing to the emergence of distinct types of scientific practice for studying these matters of concern.

If Takada captures shifts in practices for studying and reporting on plastics, then Jennifer Gabrys proposes that the multiple participants involved in working through and variously breaking down plastics might also begin to be taken into account in the emerging plastic environments of oceans. 'Carbon workers' is a term that she adopts to develop a strategy for making evident the multiple more-than-human entities that are working through leftover plastics that collect in seas, and to describe the practices, processes and politics that emerge when oceans are effectively reconstituted through plastics. In the final chapter of this section, the ways in which plastics are not just external objects of study – epitomizing consumer cultures of disposability – but also material agents that rework bodies and environments, become increasingly evident. What are the practices that sustain our plasticized bodies and environments, and what are the consequences of these entanglements as plastics and plasticizers circulate, break down and transform bodies and environments over time?

In this range of plastic encounters, objects and events, we begin to assemble an account of plastic as a transformative, multiply constituted material that contributes to the emergence of distinct types of practices and political engagements. The plasticity of plastics – as a material in process – emerges and generates distinct responses as captured here, whether through interdisciplinary study, creative practice or proposals for political action. If this edited collection brings one thing to the multiple engagements with plastics that have been generated over the decades since its post-war proliferation, it is to ask how plastics as a material-political force will spark new types of collective engagements with our contemporary and future material worlds.

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Part I

Plastic materialities

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1 Plastics, materials and dreams of dematerialization

Bernadette Bensaude Vincent

'Plastics happen; that is all we need to know on earth.' This remark is extracted from *Gain*, a novel by the American writer Richard Powers (1998: 395). The novel gives an account of a successful family business that has grown into an international chemical company. A woman, Laura Bodey, who lives nearby the chemical plant, finds she is dying from ovarian cancer, which is presumably induced by substances produced by the company. To her ex-husband, who has advised her to sue the company, Laura replies that, even if the products manufactured by this plant did actually cause her condition, they have given her everything else and moulded her life. It is therefore impossible to balance the costs and gains of plastics. In her view, it does not make sense to blame plastics because they are an integral part of our world, of our lives.

In quoting Laura's reply in *Gain*, Philip Ball (2007: 115) comments that, 'Plastic stands proxy for all our technologies: Plastics generated an entire industrial ecosystem, a technological large-scale-system, which can no longer be controlled'. Taking Ball's stance in a different direction, in this chapter I will argue that plastics have also shaped a new concept of technological design and a specific relation between humans and materials. In particular, they have encouraged the dream of dematerialized and disposable artefacts.

Plastics are more than just ubiquitous manufactured products that are used all over the world. As plastics began to spread in the daily experience of billions of people, new concepts of design were developed that reshaped our view of nature and technology. The phrase 'Plastic Age' – often used to characterize the twentieth century – has been modelled on the epochal categories of Stone Age and Iron Age. Such phrases suggest that the materials used for making artefacts shape civilizations, and that new materials propel a new age. Although our experience of materials is often occulted in daily life by the prevalence of the shapes and functions of the artefacts we use – phones, computers, automotive cars, aircraft – materials *do* matter. They are the core of technological advances and artistic creations; they drive economic exchange and the social distribution of wealth. Each substitution of a material for another one – for instance, iron, aluminium and plastics – engages new relations between nature and artifice, and determines specific relations between science and technology. Cultural historians have described the interaction between plastics and American civilization. For Robert Sklar (1970), the Plastic Age started after World War I when the traditional values of refined society gave way to mass culture, while Jeffrey Meikle (1995) convincingly argues that plastics gradually came to be identified with the American way of life and culture in the second half of the twentieth century, with the emergence of new aesthetics and new societal values.

This chapter aims to provide a better understanding of the interplay between the materiality of plastics and their anthropological dimensions. Previous materials, such as glass, wood and aluminium, are referred to by the name of the stuff of which they are made. By contrast, the common name of synthetic polymers derives from one of their physical properties. The adjective 'plastic' may be a predicate of humans as much as it is of things. The phrase 'Plastic Age' was already in use in the 1920s in the title of a film, and seems to refer to the malleable teenage years, when someone can be changed through life experience. A few years later, in his *Chemistry Triumphant*, William J. Hale announced the 'Silico-Plastic Age' (Hale 1932). The linguistic preference for the term 'plastic' is an indicator that plasticity gained a cultural meaning in the twentieth century. This requires a closer look at the physical and chemical properties of the class of materials gathered under the umbrella 'plastics', as well as at their production process. The entanglement between material, technical and cultural aspects shapes artefacts themselves, and reconfigures the relationship between nature, artefacts and culture.

Following a brief historical sketch about the emergence of plastics-as-plastics and reinforced plastics, the chapter will describe how synthetic polymers contributed to the emergence of a new relationship between technology and matter as they generated the concept of materials by design and 'materials thinking' – a new approach to materials in technological design. The next section looks more closely at the cultural values associated with the mass consumption of plastics, such as lightness, superficiality, versatility and impermanence. I will emphasize the utopian dimension of plastics and the striking contrast between the aspirations to dematerialization or impermanence and the neglected process of material accumulation upstream and downstream, which are respectively the precondition and the consequence of the Plastic Age. Finally, taking up the traditional issue of the relations between the natural and the artificial, I will consider how plastics are reconfiguring the contemporary vision of nature.

Expanding technological capabilities

In the twentieth century, plastics have replaced and displaced wood and metals in many commercial applications. This was by no means a natural and easy movement of substitution. While natural gums and resins such as *gutta percha* were manufactured in the nineteenth century for their insulating properties in electrical appliances, semi-synthetic polymers – such as Parkesine, presented by Alexander Parkes at the London World Exhibition in 1862, and the celluloid manufactured by John Wesley and Isaiah Hyatt in the 1870s – were promoted as alternatives to more conventional solid materials. Lightness and versatility were their most striking novelty. Celluloid was described as a 'chameleon material' that could imitate tortoise-shell, amber, coral, marble, jade, onyx and other natural materials. It could be used for making various things, such as combs, buttons, collars and cuffs, and billiard balls. However, as the historian Robert Friedel (1983) argues, Parkesine and celluloid did not bring about a revolution and did not easily overtake more traditional materials. Celluloid was viewed as just one of myriad 'useful additions to the arts' (Friedel 1983: xvi). Iron, glass and cotton continued to be produced in the millions of tons, while the light celluloid never exceeded hundreds of tons. In addition, the fact that celluloid made out of cellulose and camphor could be given a variety of shapes, colours and uses did not strike consumers as a sign of superiority; on the contrary, its versatile and multipurpose nature was viewed as a major imperfection.

The alliance between one material and one function – still visible in common language when we use phrases such as 'a glass of wine' – was seen as a mark of superiority. This traditional view of nature was reminiscent of Aristotle's view when he claimed that the knives fashioned by the craftsmen of Delphi for many uses were inferior to nature's works because 'she makes each thing for a single use, and every instrument is best made when intended for one and not for many uses' (Aristotle n.d.: 1252b). In this traditional view, multifunctional instruments are for barbarians who don't care for perfection, whereas distinction and discrimination signify the perfection and generosity of nature. Eventually – and despite its flammability – celluloid managed to win a place on the market when it was recognized that it was ideal for a number of applications, such as photographic films. Materials meeting all demands, purposes and tastes were not regarded as dignified. Far from being praised as a quality, plasticity was the hallmark of cheap substitutes, forever doomed to imitate more authentic, natural materials. It is only in retrospect, in view of the ways of life and the values generated during the Plastic Age, that we have come to value multifunctional artefacts.

Today, plastics are no longer considered cheap substitutes. They are praised because they can be moulded easily into a large variety of forms and remain relatively stable in their manufactured form. Certainly, the success of plastics-as-plastics is due to the active campaigns of marketing conducted by publicists who promoted them as materials of 'protean adaptability' that could meet all demands and bring comfort and luxury into everyone's reach (Meikle 1995). Chemical companies in America presented plastics as a driving force towards the democratization of material goods. In the 1930s, chemical substitutes were also praised as pillars of social stability because they provided jobs and fed the market economy: 'a plastic a day keeps depression away' (Meikle 1995: 106).

Enhancing the performances of plastics

In addition to the social benefits expected from plastics, a number of technical aspects related to their process of production account for plastics overtaking more traditional materials. Wood and metals pre-exist the action of shaping them: wood is carved or sculpted; metals are ductile and malleable – they melt at high temperatures, then the molten metal can be cast in a mould or stamped in a press to form components into the desired size and shape. By contrast, plastics are synthesized and shaped simultaneously. The process of polymerization is initiated by bringing the raw materials together and heating them – it is not separate from moulding. In more philosophical terms, matter and form are generated in one single gesture. This specific process is due to the ability of carbon atoms to form covalent bonds with other carbon atoms or with different atoms. Thus, a chain of more than 100 carbon atoms can make a single macromolecule. The resulting thermosetting polymers are rigid, with remarkable mechanical properties; furthermore, unlike celluloid they are not heat sensitive. They are lightweight, have a high strength-to-weight ratio, are corrosion resistant, remain bio-inert, and have high thermal and electrical insulation properties. However, they cannot be reheated and moulded again. Soon, a newer category of polymers came on to the market: these form weaker chemical bonds, and consequently can be reheated, melted and reshaped. These thermoplastic polymers, such as the polyethylene manufactured in the 1930s, are less rigid and more plastic than thermosetting polymers.

The synthetic polymers manufactured after World War II were already more plastic than early plastics and thermoplastics – such as polyethylene, polypropylene, polyester and polyvinyl chloride (PVC) – and undoubtedly had a wide spectrum of applications. However, the plasticity of plastics can still be enhanced because various ingredients are added to the raw materials and included in the process of polymerization. Pigments were regularly added to produce a variety of colours, which became a distinctive feature of plastic materials in the 1930s. Inorganic fillers of silica were also used to make cheaper materials. Other additives can improve various properties: thermal or UV (ultraviolet) stabilizers increase resistance to heat and light; plasticizers are added to make them more pliable or flexible (Andrady and Neal 2009); improved mechanical properties are obtained thanks to the addition of reinforcing fibres. Glass fibres were first added to reinforce plastics in the 1940s for military applications such as boats, aircraft and land mines (Mossman and Morris 1994). Reinforced plastics enabled expansion of the market in plastics in the 1950s for civil applications such as electric insulators and tankers. Initially, reinforced plastics were introduced for the purpose of weight saving and cost reduction in transport and handling. However, they generated a deep change in design, and facilitated a new approach to materials research.

Composites and materials by design

Because the mechanical properties of heterogeneous structures depend upon the quality of interface between the fibre and the polymer, it was crucial to develop additive substances favouring chemical bonds between glass and resin. The study of interfaces and surfaces consequently became a prime concern, and gradually reinforced plastics gave way to the general concept of composite material (Bensaude Vincent 1998). Although most commercial composites are made of a polymer matrix and a reinforcing fibre, composites may be made of metal and fibre. The concept of the composite that came out of plastics technology has been extended to all materials associating two phases in their structure where each one assumes a specific function: steel or iron is used as a support for toughness; plastics are useful for weight saving; and ceramics are included for heat resistance and stiffness. Creating a composite material means combining various properties that are mutually exclusive into one single structure. Composites were created initially in the 1960s for aerospace and military applications. In contrast to conventional materials with standard specifications and universal applications, they were developed with both the functional demands and the services expected from the manufactured products in mind. Such high-tech composite materials, designed for a specific task in a specific environment, are so unique that their status becomes more like that of artistic creations than standard commodities.

While reinforced plastics were aimed basically at adding the properties of glass fibre or higher-modulus carbon fibres to the plasticity of the polymer matrix, composites did reveal new possibilities and generated innovations. For instance, the substitution of old chrome-steel bumpers of the cars of the 1950s for plastic bumpers did not immediately entail the cost reduction that was expected because the composite had opened new avenues for change. Manufacturing and shaping the chrome steel were two successive operations; in the case of plastic they became one and the same process. Car designers were consequently free to curve the bumper along the line of the shell. Instead of a separate part that had to be manufactured independently and then welded to the car, the shell was integrated with the body of the car like a protective second skin. In addition to protection, other functions could similarly be integrated. Thus, ventilators and radiator grilles were combined with the same unit at the front. Integration proved useful because it reduced the number of parts and assembly steps. New concepts thus emerged that gradually integrated more and more functions into the same structural part. However, local change in the material structure of one part called for redesigning the whole automotive structure and, thanks to the synergy between structure, process and function, composites contributed to the development of a new specific approach to designing materials. The interaction of the four variables – structure, properties, performances and processes – is such that changes made in any of the four parameters can have a significant effect on the performance of the whole system and require a rethinking of the whole device. Engineers had to give up the traditional linear approach to innovation ('given a set of functions, let's find the properties required and then design the structure combining them'), and convert to 'materials thinking'. They simultaneously had to envision structure, properties, performance and process.

Thanks to the enhancement of the intrinsic chemical and physical properties of plastics through materials thinking, their market expanded to profitable and successful applications in transportation, sports items and a wide range of other products. Materials thinking also played a crucial part in the emergence of a new relationship with materials and matter in general. For materials designers, 'materials thinking' basically refers to a systems approach – a new method of design that takes into account all parameters simultaneously rather than sequentially. It has no connection with the phrase 'material thinking' in the vocabulary of social scientists, which mainly refers to the materiality of thinking (Carter 2004; Thrift 2006). Despite the divergence of references, the rapprochement between the two contexts is interesting in terms of opening the question of the meaning to be given to this new practice of design. Social scientists use the expression 'material thinking' in order to emphasize the active participation of materials in the mental activity of thinking. Similarly, the designers of artefacts could insist on the role of the physical and chemical properties of plastics that afford new opportunities in terms of design. They could emphasize that materials become active participants in the design process rather than passive objects of manipulation. However, in their discourse, materials have no say in the creative process. On the contrary, engineers and designers seem to emphasize that materials are no longer a prerequisite for design, as they adopt the phrase 'materials by design'. This phrase suggests that they are emancipated from the constraints and resistance of matter.

Materials themselves can be purposely tailored to perform specific tasks in specific conditions. For instance, in the 1960s, space rockets required never-seen-before combinations of properties: they had to be lightweight and resistant to both high temperatures and corrosion. Early composite materials were designed for such applications, and a number of them have been transferred successfully to everyday commodities such as sports articles or clothes. Materials are no longer a prerequisite for the design of artefacts, and would no longer limit our possibilities of creation. Thanks to the enhanced plasticity of composites, designers could feel emancipated from the constraints of matter, free to create artefacts, buildings or haute couture clothes according to their own inspiration.

Composites encouraged the quest for the ideal material, with a structure in which each component would perform a specific task according to the designer's project. Matter came to be presented as a malleable and docile partner of creation – a kind of Play-Doh in the hands of the clever designer who informs matter with intelligence and intentionality. Just like the *demiurgos* in Plato's *Timaeus*, the material engineer can impose forms on a passive, malleable *chora*. For instance, in the 1990s, a French company manufacturing sheet-moulding compounds for making composites advertised its products with the image of a plastic toy car and the following comment: 'What is fantastic with Menzolit play doughs [sic] is that one can press, inject, twist them, they lend themselves to all your ideas.' The plastic resin being shaped and informed by human intelligence becomes a smart composite material. The ad proudly concluded: 'Grey matter [is] the raw material of composite materials' (Menzolit 1995).

Designing materials with built-in intelligence is the ultimate goal of a number of research programmes launched in the 1990s. Smart or intelligent materials are structures with properties that can vary according to changes in their environment. They are plastic insofar as they can adjust to changing conditions or self-repair in case of damage. For example, materials with a chemical composition that varies according to their surroundings are used in medicine to make prostheses. This requires them to have embedded sensors (for strain, temperature or light) and actuators so that the structure becomes responsive to external stimuli.

The stuff that dreams are made of

Plasticity, the distinctive property of synthetic polymers, has permeated through culture. The French philosopher Roland Barthes (1971) devoted a few pages to plastics in his review of the mythologies of modernity. 'Plastics', he wrote, 'are like a wonderful molecule indefinitely changing' (Barthes 1971: 171–72). Plastics are shapeless; they have pure potential for change and movement. They connote the magic of indefinite metamorphoses to such a degree that they lose their substance, their materiality, to become virtual reality. Plastics have thus encouraged the utopia of an economy of abundance that could consume less and less matter by using cheap, light, high-tech plastics. Although Barthes witnessed only the debut of the flood of cheap fashionable and disposable products especially designed to become obsolete after a few uses, he saw the coming of a new relation of our culture to time. Whereas gold or diamond conveys a view of permanency and eternal faith, plastics epitomize the ephemeral, the ever changing. They invite us to experience the instant for itself as detached from the flux of time.

In his remarkable study of plastics in American culture, Jeffrey Meikle (1995) emphasizes that plastics have often been presented as 'utopian materials', and that they gradually came to epitomize a kind of dream world. Such a utopian world is played out not only in the rapprochement between plastics and Disney World, which relies on the abundance of fibreglass-reinforced polyester structures in the amusement park at Orlando, but also through the material-cultural values developed along with the use of everyday plastic objects, from BIC pens to razors, telephones and credit cards. In this way, the daily experience of plastics transformed American culture: 'Increasingly that culture was seen as one of plasticity, of mobility, of change, and of open possibility for people of every economic class' (Meikle 1995: 45). Indeed, the counter-culture movement, which criticized the American way of life, used the term 'plastic' as a metaphor for superficial and inauthentic people whose lives were driven by a passion for consumption and change.

Such critics could also point to the inherent paradox of plastics. These light, colourful and cheap materials, apparently liberated from the constraints of gravity, from rigid shapes and duration, are inextricably linked to the accumulation of huge quantities of matter and energy. As Jean Baudrillard (2000) points out, plastics instantiate the contradictions of a society oriented towards the mass manufacture of more and more disposable products. About 300 million tons of plastics are produced each year. These ephemeral commodities generate tons of durable waste, since thermoplastics can persist for extended periods of time in the environment (Barnes *et al.* 2009). From urban suburbs to the most remote places in the countryside, they have invaded the natural habitats of living species on earth and in the oceans. Furthermore, as most synthetic polymers are made out of fossil fuels, they use about 4 per cent of the world's oil in material substance (and 4 per cent of the world's oil in the form of energy for manufacturing).

Plastics irreversibly consume the vestiges of plants accumulated over thousands of years. The two processes of accumulation surrounding the short life of plastic commodities clearly indicate that their ephemeral character is delusory. Despite its hedonistic inclinations, the Plastic Age developed a mathematical notion of time as an abstract space consisting of a juxtaposition of discrete points or instants, blurring all issues of persistence and permanence. Plastics are supposed to be ephemeral only because – like the flying arrow of Zeno's paradox commented on by Bergson (1946) – they are supposed to be at rest, as moments of being. By contrast, our Plastic Age confronts the issue of duration. The ephemeral present of plastics is not just an instant detached from the past and the future. It is the tip of a heap of memory, the upper layer of many layers of the past that have resulted in crude oil stored in the depths of the soil and the sea. The cult of impermanence and change has been built on a deliberate blindness regarding the continuity between the past and the future. Plastics really belong to Bergson's (1946) duration; they cannot be abstracted from the heterogeneous and irreversible flux of becoming. The present is conditioned by the accumulated traces of the past, and the future of the earth will bear the marks of our present. While the manufacture of plastics destroys the archives of life on the earth, its waste will constitute the archives of the twentieth century and beyond.

Plastic nature

According to cultural historians, the Plastic Age culminated with the fashion for artificial fabrics, paintings and dyes. In the plastic items manufactured in the 1960s and 1970s, shining, fluorescent and flashy surfaces prevailed over the traditional preference for pastel colours that looked more natural or genuine. The cult of the artificial exemplified by Andy Warhol paintings broke with the early plastics, which desperately attempted to imitate wood, horn, shell or ivory in appearance and colour. They had no intrinsic value – they were praised only for their cheapness and their potential for the democratization of comfort. They were also occasionally valued because synthetic substitutes could spare the life of tortoises, elephants and baby seals. For instance, Williams Haynes (1936: 155) claimed that 'The use of chemical substitutes releases land or some natural raw material for other more appropriate or necessary employment'. The synthetic was thus a useful detour in the conservation and protection of nature.

The Plastic Age radically transmuted the cultural values attached to the natural and the artificial, and reinforced the cultural stereotype associating chemists with Faust or the alchemists who challenged nature. At first glance, it could be expected that, by design, the light, quasi-immaterial materials would reinforce the culture of the artificial initiated by thermoplastics in the mid-twentieth century. What could be more unnatural than composite materials as light as plastic with the toughness of steel and the stiffness or heat resistance of ceramics? Like the centaurs invented by the Ancients, they combined different species into one body, into their inner structure. They could consequently revive the mythical figures of Prometheus or Faust. Indeed, the Promethean view of engineers 'shaping the world atom by atom' has been revitalized by the promoters of nanotechnology. The slogan of the US 2000 National NanoInitiative announced an era when materials would be designed and engineered bottom-up, with each part of the structure performing a specific task (Bensaude Vincent 2010). The ambition to overtake nature with our artefacts is still very much alive today.

It is nevertheless counterbalanced by a back-to-nature movement that emerged in the 1980s. The more pressing the quest for high-performance and multifunctional plastics, the more materials chemists and engineers turned to nature for inspiration. Most of the 'virtues' embedded in materials by design – such as minimal weight, multifunctionality, adaptability and self-repair already exist in natural materials. Amazing combinations of properties and adaptive structures can be found in modest creatures such as insects and spiders. Spider webs attracted the attention of materials engineers because the spider silk is made of an extremely thin and robust fibre, which offers an outstanding strength-to-weight ratio. Wood, bone and tendon have a complex hierarchy of structures, with each different size scale – from the angstrom to the nanometre and micron – presenting different structural features. Their remarkable properties and multiple functions are the result of complex arrangements at different levels, where each level controls the next one. Nature displays a level of complexity far beyond any of the complex composite structures that materials scientists have been able to design. In addition, nature designs responsive, self-healing structures that quickly adapt to changing environments. Above all, the plastic structures designed by nature avoid the vexing issue raised by human-made plastics, namely accumulating tons of litter all around the world. They are degradable and recyclable.

Finally, what materials designers most envy is nature's building processes. Synthetic chemists managed to get polymerization and moulding, matter and form, into one single operation. Nature goes even further, thanks to the self-assembly of molecules. While synthetic polymers are built with strong covalent bonds, molecular self-assembly is a spontaneous organization of molecules into ordered and relatively stable arrangements through weak non-covalent interactions. Molecular self-assembly is extremely advantageous from a technological point of view, because it generates little or no waste and has a wide domain of application (Whitesides and Boncheva 2002). Self-assembly appears to be the holy grail for designing at the nanoscale, where human hands and conventional tools are useless. It is the key to a new age: 'The Designed Materials Age requires new knowledge to build advanced materials. One of the approaches is through molecular self-assembly' (Zhang 2002: 321).

Because molecular self-assembly is ubiquitous in nature, nature seems to capture all the attributes of plastics. Whereas in the early twentieth century natural structures were characterized as rigid, stiff, resistant and resilient in contrast to synthetic polymers, one century later the same natural structures investigated at the nanoscale are characterized as 'soft machines' (Jones 2004): highly flexible, adaptive, complex and ever changing.

Despite their admiration for nature's achievement, biomimetic chemists are not inclined to revive natural theology and its celebration of 'the wonders of nature'. Rather, biomimicry proceeds from a technological perspective on nature. Nature is depicted as an 'insuperable engineer' that took billions of years to design smart materials. They study the structure of biomaterials and the natural process of self-assembly with the conviction that nature has worked out a set of solutions to engineering problems. With its exquisite plasticity, nature affords a toolbox to inventive designers of advanced materials. Atoms and molecules are functional units useful for making nano-devices such as molecular rotors, motors or switches. Biopolymers provide smart tools: the two strands of DNA are used to self-assemble nano-objects; liposomes are used as drug-carriers. Living organisms such as bacteria are being re-engineered or even synthesized to perform technological tasks. 'E-coli moves into the plastic-age' was the title of one research news item announcing that plastics that are part of our lifestyle would be synthesized by E-coli bacteria with no waste disposal, and no more pollution or contamination of the environment (Lee 1997).

Conclusion

In following the migrations of the term 'plastic' from the realm of materials to the realm of humans and to nature throughout the twentieth century, this chapter has emphasized the interplay between materials and culture. From a view of nature as a stable, rigid order, our culture has shifted to a view of nature as plastic, versatile and based on the ever-changing arrangements of molecular agencies. The success story of plastics, which combined the specific features of synthetic polymers and the markets in which they flourished, deeply reconfigured consumer practices as well as those of design. Because plastics are objects of design, they are more than polymers. The classical terminology of polyethylene, polystyrene, polypropylene, phenol-formaldehyde and so on is not really adequate, since the properties and uses of plastics depend on plasticizers, fillers, UV protectors and the like. The traditional classifications of materials become obsolete when plasticity is so highly praised that design embraces materials themselves. Thus, plastics renewed the ambition of shaping the world according to our purposes with no resistance from nature.

This chapter has also pointed to the blind spots generated by the Plastic Age. In cultivating plasticity as a chief value, the twentieth century had to develop a sort of blindness about the impacts of material consumption on the environment and on the future. Indeed, mass consumption in general requires no concern with the afterlife of commodities, however much the cult of disposability and ephemerality associated with plastic reinforced and perpetuated this denial. The cultural history of plastics must be completed by agnotology studies pointing to the social construction of ignorance necessary for the mass diffusion of plastics (Proctor and Schiebinger 2008). This sort of ignorance is a denial – a self-deception – that allows us to live in a fool's paradise.

Although the twenty-first century seems to be more aware of environmental issues and more concerned with the future, plastics retain their utopian nature. Plastic items may have acquired a very bad reputation for many people, but the concept of plastic as malleable matter is still extremely attractive. The emerging economy of biopolymers and biofuels designed at the molecular level is based on the vision of nature as a limitless field of potentials. Design from bottom up, proceeding from the ultimate building blocks of nature, is supposed to meet no resistance and to afford a free space for creativity. It encourages the view of matter as purely plastic, passive and docile, subject to the designer's purposes. The techno-utopia of the Plastic Age is not over. It continues through the denial of the constraints imposed by matter and nature's laws. Just as 'the light dove, cleaving the air in her free flight, and feeling its resistance, might imagine that its flight would be easier in empty space' (Kant 1965: 48), contemporary designers cherish Plato's illusion that we could be free from matter and venture beyond it on the wings of ideas. In paraphrasing Kant's (1965) criticism of Plato, one could say that the Plastic Age will be over when the dove-designer realizes that resistance might serve as a support upon which to take a stand and to which he could apply his powers.

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2 Process and plasticity

Printing, prototyping and the prospects of plastic

Mike Michael

Introduction

This chapter[1] is concerned with the emerging future of plastic as it enters into the home in a new guise. With the rise of new technologies and their co-constitutive discourses, plastic is being opened up – 'democratized' – as a newly manipulable material. At the same time, this 'democratization' requires particular technical skills of production and consumption. As such, the chapter is interested in a specific material – plastic – politics in which the capacities of humans and non-humans together are reconfigured, enacted and performed in particular ways (e.g. Braun and Whatmore 2010).

Now, obviously, plastic is a long-standing cohabitant in most Western homes: it has become a stock material out of which a plethora of products are constructed, or partly constructed. A quick survey of the products in David Hillman and David Gibbs's (1998) *Century Makers: One Hundred Clever Things We Take for Granted Which Have Changed Our Lives over the Last One Hundred Years* reveals just how many have plastic as an integral component: hairdryers, toasters, washing machines, irons, frozen food, ballpoint pens, training shoes, Velcro®, child-resistant caps, LCDs. Yet these are very much *products*. They are consumables that have emerged from design houses and factory production lines. These are not easily made at home: even the smaller (plastic) component parts that go to make up the final product cannot be easily, if at all, manufactured within the domestic – or craft – sphere, as the designer Thomas Thwaites's (2011) Toaster Project, during which he attempted to construct a toaster from scratch, demonstrates only too clearly.

There is no doubt an element of stating the obvious in the foregoing, and yet it would appear that this obviousness is in the process of being overturned. In the specific instance of plastic, this seeming shift is, it can be argued, a partial outcome of the emergence of rapid prototyping or 3D printing technology that uses plastic as one of its primary materials. More specifically, the 3D printer is moving out of the domain of professionals and specialists (designers, model makers, product developers, manufacturers) and into the space of the home. Or rather, this movement is beginning to reconfigure such spaces – it is a movement that, potentially, peculiarly and problematically re-spatializes the domestic sphere and the workplace (where workplace throughout this chapter refers to industrial or manufacturing rather than, for example, office settings). Moreover, it is, potentially at least, re-articulating other 'global' inter-relations: to domesticate production is also to have an impact on contemporary global patterns of manufacturing (from China to the home) and on global ecological patterns of waste production (from the irredeemably broken to the readily reparable). The emergence of the domestic 3D printer is thus instrumental in generating a series of complex, sometimes ironic, relationalities that range across, for instance, craft and expertise, informed materials and 'disinformed' humans, consumption and production, global and local, sustainability and profligacy, expectation and fantasy.

The implications of 3D printing are clearly enormous and extend well beyond the scope of this chapter, which restricts itself mainly to a discussion on the potential impacts on the domestic user. So, in what follows, there is an initial consideration of the apparent sociotechnical position of plastic in contemporary Western societies. This leads into a discussion of the complex relations of plastic to 'plasticity', not least as these inflect with issues of spatial divisions between workplace and home, and the role of craft and skill within such divisions. In the subsequent section, the theoretical underpinnings of the chapter will be explicated and the debts to such writers as Whitehead and Deleuze laid bare. There will then be a discussion of 3D printing, especially with regard to the ways plastic has been 'eventuated' in relation to various contested futures and the contrasting capabilities of both machines and humans. In the next section, we go on to address the apparent rise of the domestic 3D printer. In light of the accompanying claims made for its utility, plastic takes on a role in the renewed blurring of the boundaries between home and workplace, production and consumption. At the same time, new boundaries look set to emerge. In the final section, the meaning of this patterning of de- and re-territorialization is further interrogated, not least in the light of other possible futures of 3D plastic printing.

So little plasticity in plastic?

Without retracing a history of plastic, we can say that plastic is a material that is quintessentially industrial. From the extraction of the source material (e.g. oil), through the chemical process of its production, and onto the procedures of design and manufacture by which plastic artefacts are made, plastic belongs to the realm of the factory. It is not a material that is easily manipulable beyond the specialist combinations of machines and humans that chemically compose and process, dye, extrude, mould and finish plastic goods. Plastic, as an icon of post-war Fordist industrialization, and even the batch production of post-Fordism, has a role in the policing of the spatial boundaries between home and factory (Lefebvre 1974).

This remoteness of plastic production, despite the many intimacies of its consumption, can be reframed in terms of the idea of craft. In the first of a series of videos that accompanied the Victoria & Albert Museum's exhibition the 'Power of Making', there is a comment by a flutemaker: 'I think craft or making things with your hands is fundamental to being human.' Of course, this can be read in a number of ways: an insistence on the dignity of a particular sort of labour; a lament over the rise and predominance of industrial or Fordist production; a definition of the human in terms of a practical – handed – engagement with the world (see Sennett 2008). Yet this all assumes that the appropriate materials and tools are to hand. Or rather, it assumes a special sort of relationality between maker, tool and material. Some materials do not lend themselves, or lend themselves in very limited ways, to the potential craftsperson. These materials can be said to be 'informed' (Barry 2005; Bensaude Vincent and Stengers 1996) insofar as, paraphrasing Barry (i.e. replacing 'pharmaceuticals' with 'plastics'):

> [Plastics] companies do not produce bare molecules … isolated from their environments. Rather, they produce a multitude of informed molecules, including multiple informational and material forms of the same molecule. [Plastics] companies do not just sell information, nor do they just sell material objects … The molecules produced by a [plastics] company are already part of a rich informational material environment, even before they are consumed.
>
> (Barry 2005: 59)

In the case of plastic, this informedness partially manifests itself through exclusion: only certain industrial actors have the capacities to make and mould plastic. The (domestic) human hand is marginalized. As hinted at above, plastic is perhaps the example *par excellence* of what, from the perspective of the domestic and of craft, is an abject relationality – the impoverished possibilities of re-inventing and re-informing plastic. In sum, plastic is a material with a 'composition' (where 'composition', read through a Whiteheadian lens, implies that the chemical properties of plastic are mediated by the co-presence of a nexus of technologies, systems, skills, environments and so on) that precludes manipulation outside of an industrial setting. Thus, while plastic affords innumerable uses in its forms, it imposes considerable constraints in its substance (see Shove *et al.* 2007).

However, we need to tread warily here. While plastic does indeed take on many discrete forms and functions, these can be domestically adapted to alternative uses. Examples abound. At one end of the spectrum there are basic reuses: carrier bags become mini-binbags; margarine tubs, yoghurt cartons, sawn-off plastic bottles become containers for screws, for nuts and bolts, for soil and seeds and so on. At another end of the scale, plastic cutlery is transformed into art, and the square cup-shaped piece of plastic that once attached a D-lock to a bike frame is turned into an elegant and efficient attachment-cum-receptacle for the supporting arms of a resurrected child's bicycle seat (though I say it myself). However, these are gross interventions: pieces, or existing shapes, of plastic are redeployed, and at most are cut or sawn or melted down to size (or glued or taped together up to size). There is no constitutive reshaping or recasting, say, of the many different bike light plastic fitments; once these break, one can't mend them, or manipulate other fitments to accommodate now fitment-less bicycle lights. The upshot is a collection of bicycle lights that either remain unused or require ad hoc forms of attachment (such as strapping to handlebars with electrical tape).

In a word, there is little plasticity in plastic, especially if we take plasticity to connote the potential for new or renewed connections to be rendered domestically (i.e. outside of a professional or industrial setting) and thus for the functions of plastic to be recovered or altered or adapted or invented. This differs somewhat from, but also supplements, Bensaude Vincent's (2007) formulation of plasticity, which, within a discussion of the changing borders between the natural and the artificial, places its emphasis on the mass production of polymers and the rise of the Plastic Age with its profusion of plastic goods. Accordingly, 'plasticity' signifies the multiplicity of goods and functions that a single material (or, rather, class of materials) can yield. By contrast, nature was marked by inflexibility and limitation.

In the present analysis, the notion of plasticity is partly developed with reference to localization in neurophysiology, where function is mapped onto particular locations on or within the brain such that if a particular area is damaged or destroyed then there is a permanent loss of the correlated function. If the part of the cortex responsible for a specific set of movements is destroyed through stroke, say, the capacity for that movement is lost. By contrast, plasticity allows for neural adaptation in which new connections can be made that 'correct' for the damaged or destroyed area and enable lost functions to be, more or less, recovered. In the case of motor-neurone damage, it has been found that adjacent undamaged areas take over the work of the damaged area.

However, we should take heed of Susan Leigh Star's (1989) observation that the comparative privilege enjoyed by theories of plasticity versus locationalism reflect and mediate the particular sociomaterial conditions of the time (e.g. World War I renders locationalism more 'useful' as a way of dealing – coping – with, and treating, the enormous number of brain-damaged soldiers returning from the front; arguably modern neuroimaging techniques such as fMRI and PET are instrumental in the apparent contemporary resurgence of locationalism). The general point here is that plasticity is itself a plastic concept, its content and utility varying under different circumstances. The present aim is not to map or typify the versions of plasticity but merely to trace some of the specific ways in which the plasticity of plastic might be undergoing change through an emergent nexus of sociomaterial relationalities associated with 3D printing.

Above I argued that we needed to be circumspect about the plasticity of plastic as we move from form to substance, or from the production of variety to the consumption of specific plastic artefacts. However, a note of caution now needs to be sounded. Drawing on a different literature, we can say that the use of plastic tends toward 'standardization'. Its function is scripted (Akrich 1992; Akrich and Latour 1992) into the objects of which it is a part. There is a specified and necessary range of capacities and skills 'built into' (the functioning of) the plastic child-proof bottle cap. Of course, as Latour (1992) has pointed out, these scripts also serve to discriminate against certain bodies – sometimes these discriminations are positive (as in the case of children, obviously enough), sometimes they are negative (as is the case for elderly people with less strength or mobility in their hands). Further, though, such mundane technologies can also invite a certain sort of craft: for instance, they can be used to precipitate resistance, subversion or protest, that is to engender sociomaterial innovation (Michael 2000a).

In addition, there is also the matter of aesthetics (or the aesthetics of matter) to take into account: there is a craft to 'how' one opens a child-proof cap that is partially captured by such terms as elegance, skilfulness, style. This simply points – as much recent literature on consumption does (e.g. Lury 1996) – to the performativity of engagement with objects, plastic or not. Use is as much about expression as utility, and as such it performs not only practical functions but also social relations (often indissolubly so). This performativity is evidenced even in those plastic technologies that seemingly require no skill at all. Michael (2006; also see Halewood and Michael 2008) has suggested that Velcro® is emblematic of unproblematic functionality: as it says on the Velcro® website in relation to Velcro® packages, these are 'designed and engineered for all ages and motor skill levels'.[2] Yet problems abound. Indeed, to make Velcro® work seamlessly, or skill-lessly, a lot of craft has sometimes to be mobilized. Michael recounts the frequent episodes with his daughter when her fine hair would get caught in the Velcro® strips that were attached to her cycling helmet. Over time, and with considerable negotiation, movements became mutually choreographed so that, with some craft, hair and Velcro® remained disconnected. This was a delicate, shared reconfiguration of comportments – it was a collective sociomaterial performance (or instance of heterogeneous performativity) in which not only function but also, indissolubly, an emerging relationship between daughter and father was enacted (also see Mol 2002).

In this section, we have considered how plastic can be portrayed as a material that has served in the differentiation of the sociomaterial spaces of industrial workplace and home, and between the practices of production, craft and consumption. At the same time, we have also noted that these divisions are not simple: that craft attaches to the way that even the most mundane and putatively skill-less plastic artefacts are put to work, not least when craft is understood in terms of a heterogeneous performativity that straddles both the practical and the expressive. As such, we have moved from a view of plastic that, within the confines of the everyday, has a diminished plasticity, to a vision of plastic as occasioning numerous 'small' relationalities that make up a sort of subterranean plasticity in which minute, often unnoticed or unremarked, adaptations and innovations are instituted as a matter of routine. Ironically, these little plasticities serve in the reproduction of plastic's lack of plasticity (see Bowker and Star 1999) – that is to say, they reinforce the impression of plastic's limited plasticity in everyday life. In the next section, we consider how we might better theorize this dynamic, especially in light of the emergence of rapid prototyping or 3D printer technology that can be used to make plastic objects.

From plasticity to plastic event

In the previous section, an attempt was made to understand plastic in terms of its reflection and mediation of particular spatializations (domestic/industrial) and comportments (craft-ful/skill-less). The outcome was a complication of these categories: craft was found in skill-lessness, and consumption of the domestic sphere inflected (to some extent) with the production of the industrial (on this score, also see Cowan 1987). In part, this complication arises because the discussion has been premised on the assumption that there is such a thing as 'plastic' per se. The proliferation of counter-examples and contingencies above indicates that plastic, like all entities, is perhaps more fruitfully regarded in terms of process: it is something that emerges in events – it is eventuated. This formulation derives from the process philosophies of A.N. Whitehead and Gilles Deleuze. Without entering into details, we can propose that what plastic is – its ontology – rests on the sorts of events (actual occasions) of which it is a part and out of which it emerges, and thus on the various social and material elements (prehensions) that come together and combine (concresce) within that event (Whitehead 1929; also Halewood 2011). As such, 'plastic' is always eventuated in its specificity: in other words, there is no abstracted plastic per se to which qualities such as cold, or green, or flimsy, or industrial are attached. Rather, there is flimsy plastic, or green plastic and so on; and any abstracted plastic is itself abstracted in its specificity, say by a chemist or an historian or a designer.

This schema allows us to move away from the abstraction of plastic that was deployed above, and to focus on its concrete eventuations. However, we do need to unpack a little further the notion of event that is being used here. The entities within the event are not simply 'being with' each other, they are also in a process of 'becoming together' (see Fraser 2010) – rather than interacting, they intra-act (Barad 2007). Put another way, there is always an element of uncertainty or openness about the event as the elements become together – what the event 'is' is immanent, it is open to the virtual, subject to de-territorialization – at least in principle (see, for instance, Massumi 2002; DeLanda 2002; Bennett 2010).

Or rather, there are parallel processes of de- and re-territorialization: events simultaneously 'open up' and 'close down'. As Deleuze and Guattari (1988: 10) frame it, 'How could movements of deterritorialization and processes of reterritorialization not be relative, always connected, caught up in one another?' For these authors:

> there are knots of arborescence (rootishness) in rhizomes, and rhizomic offshoots in roots. Moreover there are despotic formations of immanence and channelization specific to rhizomes, just as there are anarchic deformations in transcendent systems of trees, aerial roots and subterranean stems. The important point is that the root-tree and the canal rhizome are not two opposed models: the first operates as a transcendent model and tracing, even if it engenders its own escapes; the second operates as an immanent process that overturns the model and outlines a map, even if it constitutes its own hierarchies, even if it gives rise to a despotic channel.
>
> (Deleuze and Guattari 1988: 20)

This seems particularly pertinent in relation to the ways that events are often partly constituted of enunciations (e.g. narratives, theories, motifs, discourses, slogans, abstractions) that are designed to characterize definitively those events – to territorialize them in particular ways. However, the relation of such enunciations to events are highly complex. Despite themselves, they become 'embroiled' in the event and at once close it down and open it up. Michael and Rosengarten (n.d.) discuss this complexity with regard to the discursive abstractions of the 'gold-standard-ness' (broadly meaning scientific excellence) of randomized controlled trials of pharmaceutical prophylactics for people at high risk of HIV infection. In their analysis, an abstraction acts, and is enacted, in a variety of contrasting ways. First, it is an attractor – a sociomaterial 'aspiration' – toward which an event is moving. It is a specific, virtual prospect which the concrete event is seen to be in the process of realizing. Second, an abstraction is a key element in the concrete making of the event – it is a type of account that contributes to what the event is. Third, in the complex specificity of an event, an abstraction is itself emergent – what that abstraction 'is' is eventuated within and through the specific contingencies and exigencies of the event. Fourth, an abstraction is an ironic element in the problematization of the event – it is a spur to the de-territorialization of the event that lures something 'other', a sort of anti-attractor. In sum, an abstraction at once (i) characterizes an event, (ii) is a component of an event, (iii) emerges through that event, and (iv) precipitates other abstractions that differ from or counter it.

As we shall suggest below, this fourfold schema applies to the particular eventuations of the 3D printing of plastic objects. What amounts to 3D printing is at once commonsensical and fantastical, easy and difficult; and plastic is a matter of opening up and closing down (for a similar discussion of the designed 'thing', see Storni 2012).

The rapid rise of rapid prototyping

Rapid prototyping is a generic name given to a form of additive manufacturing where layers of a material are deposited and fixed on top of one another in order to reproduce a shape that has been determined using computer-aided design (CAD) systems. The materials can vary (e.g. metals such as titanium, or paper, or resin), as can the specific processes of addition and adhesion (e.g. electron beam melting, stereolithography), but here the focus will be on those versions that use plastics (e.g. polylactic acid or polylactide (PLA) and acrylonitrile butadiene styrene (ABS)), and methods such as fused deposition modelling in which a nozzle directs melted plastic (down to the scale of fractions of a millimetre) onto a support platform, where it builds up into the required shape layer by layer.

This technology has been available for some 20 years or so and has been mostly used in industrial and design settings where prototypes (or the components of an artefact in development) can be rapidly produced, and materially examined for fit, aesthetics, usability and various other properties. The key advantage afforded by rapid prototyping is that designers and engineers can quickly and cheaply mock up a given component or artefact and discuss it with the various members of the design or production team. As it was framed in *The Economist* (2011), 'It enables the production of a single item quickly and cheaply – and then another one after the design has been refined'.[3] The upshot is that the process of product design is considerably and cost-effectively accelerated.

Increasingly, however, it seems that this technology is moving toward manufacturing as well as prototyping. Such are the improvements in 3D printing that it:

> is starting to be used to produce the finished items themselves … It is already competitive with plastic injection-moulding for runs of around 1,000 items, and this figure will rise as the technology matures. And because each item is created individually, rather than from a single mould, each can be made slightly differently at almost no extra cost. Mass production could, in short, give way to mass customisation for all kinds of products, from shoes to spectacles to kitchenware.
>
> (*The Economist*, 2011)[4]

Here we have a re-vivified realization of post-Fordist production (e.g. Lash and Urry 1987) where customization of manufactured products can become an inexpensive matter of course. Indeed, it has been suggested that, with the diffusion of 3D printers, there is potentially a movement towards what Craig Allison and his colleagues (n.d.) call a 'hybrid of the consumer/producer dichotomy, a prosumer society … wherein the roles of the consumer and producer merge'.[5]

Having noted this, when following up some of the comments on *The Economist*'s website, we can note that this vision of the future is not an unproblematic one. In reaction to a similar article entitled 'The Printed World: Three-dimensional Printing from Digital Designs Will Transform Manufacturing and Allow More People to Start Making Things' (*The Economist*, 2011),[6] a number of sceptical comments were posted. The first two query the claims made for 3D printing and its supposed advantages over traditional methods of manufacture:

> Nothing really has changed in the last 20 years – it is still a niche as output is to [sic] low, cost high or properties are not met. Too much enthusiasm for something that has obvious inherent problems such as low structural strength and slow production times. Who knows where this will be in 10 or 20 years, but for now it is an amusing sidebar merely. The article does not show the full picture, it misses the advances of foundries, fast milling machines, laser machining etc.
>
> 3D Printing is as close to the market as as [sic] the translation of the Genome project's insights into effective medicines to cure cancer. Watch the hype![7]

These comments reflect how the expectations raised by the enthusiasts for, or advocates of, this or that technology precipitate a negative reaction – the accusation that the claims are fanciful, unrealistic hype (e.g. Brown 2003). Implicit here is a wariness toward the particular performativity of these claims – they are as much concerned with enabling a given future (by generating enthusiasm and, indeed, markets) as depicting it (see Michael 2000b). With these claims and counter-claims, plastic is specifically eventuated (on *The Economist* website) as both a medium for the bespoke manufacture of a multiplicity of objects (de-territorialization, high plasticity in Bensaude Vincent's sense of a material that can be turned into more or less anything) and a material hampered by the limitations of a technology which can, as yet, only produce 'sub-standard' artefacts (re-territorialization, low plasticity in the sense of still failing to realize this promise or prospect of multiplicity).

Here are two more contributions to *The Economist* comments page:

> OK – making progress toward replicators. How's it going with transporters?
>
> we can print out chicken to eat!

In these two cases, there are more and less explicit references to the replicators of *Star Trek*. A replicator is staple technology on the *Star Trek* family of TV and film series, which can fabricate (usually) food (and its receptacles) within a few moments of being verbally commanded to do so. These website comments are, obviously enough, meant to be humorous: they gently and ironically mock the aspirations of those who promote the 3D printer. Yet the term 'replicator' seems to have considerable currency in discussions of the 3D printer. For instance, on a 'dornob: design ideas daily' webpage there is the following headline: '3D Printer + DIY Home Factory = Real-Life Replicator.'[8] On the iTWire (connecting technology professionals) website can be found the recent headline: 'Star Trek Replicator: 21st Century Version Might be 3D Printer'.[9] Finally, the start-up company MakerBot has named its new two-colour 3D printer the 'Replicator'.[10]

Inevitably, the web coverage of MakerBot's innovation has not been shy of referencing *Star Trek* (e.g. 'MakerBot Replicator Beams In'; 'MakerBot Replicator: Out of Star Trek into Your Own Garage'). This connection with the future is certainly present in the MakerBot Replicator's own maker's accounts. For instance, MakerBot's chief executive Bre Pettis has claimed that 'It's a machine that makes you anything you need', and is hopeful that 'if an apocalypse happens people will be ready with MakerBots, building the things they can't buy in stores. So we're not just selling a product, we are changing the future', which includes putting 'MakerBots on the moon (to build) the moon base for us'.[11]

These references to science fiction(-become-fact) eventuate the 3D printer and plastic in a number of ways. The replicator is an abstraction that opens up the eventuation of the 3D printer – that is, the replicator points it toward a particular virtuality (or serves as an attractor or sociomaterial 'aspiration' for the 3D printer), wherein the local production of anything becomes feasible. There is, in other words, the prospect of 'everything-ness' that attaches to the domestic 3D printing of plastic objects. At the same time, the replicator serves to characterize the 3D printer in the here and now, while simultaneously being instantiated by – emerging in its specificity through – the 3D printer. Finally, as we have seen, the 'ingression' of the replicator into the eventuation of the 3D printer also triggers a negative reaction – the associations with science fiction serve simply to underscore the fictional, even fantastical, status of the prospective futures of this technology.

Relatedly, part of the attraction of 3D printers lies in their apparent ease of use – one's CAD designs are seamlessly relayed to the printer through the computer. Indeed, in the various *Economist* comments, it was notable how, despite the criticisms, this ease of operation was assumed – but then many of the posts were from engineers presumably familiar with CAD-like systems. The *Star Trek* idealization of the 3D printer simply builds on this: instructions can be directly conveyed through speech. Oddly enough, it is in *Star Trek* itself where this simplicity of operation is ironized. In an exchange between Tom Paris and the replicator (in the episode 'Caretaker' of *Star Trek Voyager*), it becomes clear that even apparently mundane instruction giving requires an element of skill – instructions need to be highly explicit if they are to be actionable by the replicator. When Tom Paris issues an order to the replicator for tomato soup, the replicator keeps returning with a series of options for different and more specific sorts of tomato soup. The increasingly frustrated Paris ends up growling at the replicator for what seems to him to be the obvious sort of tomato soup – plain and hot. A comment on the same YouTube page parodied the exchange: 'i changed my mind i want pizza now; There are 140 different kinds of …' Tom Paris' annoyance evokes the prospect that, every time one uses a replicator, it would be like entering into a Garfinkelian breaching experiment (Garfinkel 1967), in which what is normally implicit in smooth social intercourse is made frustratingly and disruptively explicit (thus revealing what is implicit). Put another way, specificity in instructions is thus a technically demanding skill.

Home is where the 3D printer is …

The 3D printer, it would seem, is about to become a household item. To read through the various press releases, publicity materials and exhibition reports around these new products is to be left with the impression that their arrival in the home is imminent. This imminence rests on a number of factors: the decreasing costs associated with 3D printers; the convenience of making objects and components that are otherwise unobtainable or hard to obtain; and the ease with which they can be used.

We have seen already how it is claimed, albeit hyperbolically, that the MakerBot Replicator can make anything, but, additionally, it is also asserted that this can be done easily: as it says on MakerBot's website: 'When you get your MakerBot Replicator™, you'll have your machine up and running in no time.'[12] Similar declarations are made for the UP! 3D Printer, which is 'The world's first new standard in personal Desktop 3D printing in price, performance and ease of use!'[13] This sense of the 'ease of use' is reinforced by Dejan Mitrovic's 'Kideville' activity at the Victoria & Albert Museum's 'Power of Making' exhibition, where children were invited to help produce a model city by designing their own house, which was then 3D printed. In sum, in addition to the prospect of 'everything-ness', there is also the prospect of 'easy-ness': anything can be made by anyone, anytime, anywhere.

However, there is much here that is not so 'easy'. First, there is the matter of preparing the designs for 3D printing. As noted, this requires some expertise with CAD systems. In some cases, designs may be downloaded from open-source libraries made available by the 3D printer manufacturer. However, given that one of the key selling points of the 3D printer is customization, one would expect that a facility with CAD is necessary. This seems to be glossed over in many accounts of 3D printers.

Dejan Mitrovic describes the process of Kideville thus:

> I encourage (the children) to split the paper (on which they sketch their picture of a house) into 4 parts so that they think about the different views of the house, so the front view, the side view, the top and then a 3D view. Once they've done that, it helps them understand what their idea is,

> and what they want their idea to look like, and then they move onto the computer where they use special 3D software and quickly design it, mock it up in the CAD and then make a 3D file. After that, I take the file, put it onto the printer and it prints their house out of plastic.[14]

The 3D printer and plastic together become, that is to say, are enacted as, in Bruno Latour's (2005) terms, an intermediary that unproblematically transforms ideas into material objects without deviation or corruption. Yet the 'special 3D software' serves more as what Latour calls a mediator: it realizes individuals' plans in the light of its own particular capacities (as well as in reaction to the capabilities of its users). As such, what seems to materialize is a 'mock up' – an 'estimated' version of the planned object. In this particular eventuation of plastic through the 3D printer, it becomes a material of ready manipulation (a matter of child's play). Yet this is only possible because of the co-presence of a set of skilled practices: drafting and modelling skills (making Plasticine models was also part of Kideville); design skills (thinking about different views of the home); CAD skills; and crafting skills (detaching the plastic objects from the 3D printer, cleaning the object up – see below). At each of these practical junctures, there is a translation of the 'idea' of the house into the emerging plastic house.[15]

In a showcase video for the UP! 3D printer, a child takes her broken robot toy to (presumably) her grandfather. The foot has come off. Grandfather astutely notes that the other foot is identical, so detaches it from the robot and using a digital LCD Vernier calliper takes a number of measurements. The next shots are of the virtual foot taking shape in the CAD system (we are not told how the measurements are transferred from calliper to computer). The final version of the virtual foot is placed within a virtual printer space, and the print command clicked. Two children are then shown looking eagerly at the UP! 3D printer in operation. In a subsequent shot, the completed white plastic foot is shown held in one hand while a second hand using pliers prises a thin sheet of unwanted support plastic from the sole. (A similar but more extensive cleaning-up process is shown in another demonstration video for the UP!, where the excess plastic is removed from a ball bearing using both pliers and an awl tool). The foot is then painted black, attached to the robot, and tested for vertical movement by being swivelled up and down on the ankle joint. When the feet are seen together frontally, it is obvious which is the homemade foot (the replacement foot appears lopsided, and it is more matt in colour). The repaired robot is restored to its delighted owner, who exercises it excitedly.[16]

Again we glimpse a complex of complementary skills and capacities necessary for the making of the 3D printed plastic objects. In addition to design, CAD and crafting skills, there are, in this instance, measuring and finishing skills to be taken into account (the latter being especially necessary where the comparatively low resolution of the 3D printer produces an extruded plastic object with a rough surface that requires filing and sanding). In consulting a designer colleague with very considerable experience of 3D printing, it became apparent that a good deal of unexplicated practical expertise and skill was needed for the imagined plastic object of desire to be translated into a printed plastic product.

In summary, we can now draw out a fourfold analysis of (the abstraction that is) ‘easy-ness’ and its place in the eventuation of 3D printing and its plastics. As such, we can note that ‘easy-ness’: (i) operates as a tendency that is an attractor toward which 3D printing and its plastics are moving; (ii) serves to characterize the actual operation of 3D printers (this is the way that 3D printers really function); (iii) is also emergent in relation to the contingencies of 3D printing (we see that what counts as a manifestation of easy-ness is up for grabs depending on how an event of 3D printing turns out); and (iv) precipitates a counter-reaction that questions the sociomaterial meaning of the abstract idea of ‘easy-ness’.

Concluding remarks

This chapter has attempted to trace the eventuation of 3D printing and plastic in terms of process and plasticity. The argument builds on Bensaude Vincent’s (2007) version of plasticity as the pluralization of objects on the basis of the particular capacities (informedness) of plastic – what has here been called ‘everything-ness’. In addition to pluralization, there has also been a supplementary emphasis on ‘easy-ness’ – the making of such a plurality of plastic goods by anyone, anywhere, anytime that has been mediated by the supposed establishment of 3D printing. However, these dual axes of plasticity are, it has been argued, embroiled in the complex processes entailed in the specific and concrete eventuation of 3D printing and its plastic. Developing a fourfold analytic of the event, or rather of eventuation, it has been suggested that these axes serve simultaneously as tendencies or attractors (prospects or virtualities), as actual contributions to the characterization and instantiation of the 3D printing and its plastic artefacts, as characterizations that are themselves contingently emergent through these instantiations, and as prompts for, or evocations of, the ‘other’ where the axes are problematized (a few things in a few places, rather than everything everywhere).

In terms of the relationship between the 3D printer and sociomaterial respatialization, we propose that the proclaimed collapse of the distinction between domestic and manufacturing or design spaces (and between producer and consumer bodies) might be overstated. Or rather, there is a reconfiguration of these: a space like the ‘home post-Fordist factory’ rests on the availability of an array of skills – skills that are partly enabled and mediated by the porosity of the home – not least to various knowledges (e.g. access to open-source CAD libraries, websites such as Shapeways[17] on which 3D designs are traded). In other words, the domestic operation of the 3D printer still relies on a ‘centre of design expertise’ even if that centre is virtual. However, we might also tentatively predict that there will emerge something like a punctuated, circulating expertise or skilfulness as accumulated experience and novel domestically derived designs come to disseminate across the web (and possibly go viral). In other words, we might imagine less a dramatic collapse of the spaces of the 'domestic' and the 'industrial' than a complex shifting interdigitation, one that will be rendered still more complex as the 3D printer itself comes to be 3D printable at home.

Needless to say, the current discussion has been a rather limited one, structured by concerns with the eventuation of plastic in manufacturing, design and domestic spaces (everything-ness), and the relation of such making to skill or craft (easy-ness). Another route might have taken in issues of intellectual property rights (IPR). Might the copying and making of the components of everyday technologies (the cooker knob crops up several times, and is a trial product in one of the UP! promotional videos) infringe the Registered Designs Act, Unregistered Design Right, copyright on 3D Printer Design Files, or the Patents on the technology? As it turns out, in the UK at least, all this is unlikely to be the case (Bradshaw *et al.* 2010). However, if 3D printing were to become highly popular, there is no guarantee that design and manufacturing professional associations will not start lobbying for additional IPR protections. If new IPR measures are put in place, this might conceivably prompt another set of skills (as we see with music file sharing). This possible eventuation of 3D printing and its plastic through the intra-actions of IPR and their infringements are perhaps prefigured in the recent case of the 3D printing of the standard key for Dutch police handcuffs (derived from a high-resolution photograph of the key as it hung from a police officer's belt). The file for the key was put online, rendering Dutch handcuffs potentially useless.[18]

One of the issues that was briefly mentioned above but is otherwise absent from the discussion is the relation of 3D printing to the environmental problems posed by plastic. Given the still emergent character of 3D printing, we can only hint at its implications for the environmental impact of plastic. To start, we can note that *professional* 3D printing can be understood to eventuate plastic in relation to environmental matters of concern in contrasting ways. On the one hand, it can save on the financially and environmentally costly processes of making prototypes through retooling machines on the factory floor; on the other hand, it can encourage designers to 3D print a series of prototypes as the design is progressively – in cheap but environmentally wasteful piecemeal steps – refined (although one of the plastics that is typically used, PLA, is derived from corn starch or sugar cane, and is biodegradable). In relation to the *domestic* 3D printer, there are many additional environmental issues to unpack, such as: learning to do 3D printing entails waste (over and above the almost inevitable mistakes and false starts, freshly 3D printed objects arrive with excess plastic that needs to be removed); there is a 'hobbyist' temptation to make per se, where the act of production is also the act of consumption, and the means of 3D printing (rather than the finished articles) become the end; homemade plastic objects increasingly flow into local (gift) economies as they carry the additional value of 'handcrafted' and become acceptable as presents, keepsakes, mementos and so on. Conversely, as noted briefly above, 3D printing can resource the repairability of plastic objects: no longer the ease of transition from utility to waste.

This potential proliferation of plastic stuff is, of course, grounded in the plasticity of plastic mediated by domestic 3D printing. However, perhaps what is at stake here lies less with 3D printing per se, and more with its (projected) domesticity. The abstractions of everything-ness and easy-ness that attach (albeit, as we have seen, problematically) to the domestic 3D printer serve to individualize production as if it were in principle a good thing when 'production tools become democratized'.[19] Here, to 'become democratized' means to 'become domesticated'. Put another way, this can be understood as another neo-liberal twist in which people are faced with the environmentally charged 'choice' of using 3D printers simply to consume more stuff (make new objects, making as consumption) as opposed to making in order to consume less stuff (by extending the lives of their existing plastic goods).

Notes

1 The author would like to acknowledge the advice and help of Andy Boucher and David Cameron.
2 www.velcro.co.uk/index.php?id=124 (accessed 27 February 2012).
3 www.economist.com/node/18114327?story_id=18114327 (accessed 22 February 2012).
4 www.economist.com/node/18114327?story_id=18114327 (accessed 22 February 2012).
5 Allison, C., Davies, H., Gomer, R. and Nurmikko, T. (n.d.) 'What are the Implications of Personal 3D Printers Becoming Domestically Available?' eprints.websci.net/8/1/comp_6048_3d_printing.html (accessed 25 February 2012).
6 www.economist.com/node/18114221 (accessed 22 February 2012).
7 Both quotes at www.economist.com/node/18114221/comments#comments (accessed 22 February 2012).
8 dornob.com/3d-printer-diy-home-factory-real-life-replicator/ (accessed 22 February 2012).
9 www.itwire.com/science-news/energy/48686-star-trek-replicator-21st-century-version-might-be-3d-printer (accessed 22 February 2012).
10 www.makerbot.com/blog/2012/01/09/introducing-the-makerbot-replicator/ (accessed 22 February 2012).
11 www.bbc.co.uk/news/technology-16503443 (accessed 24 February 2012).
12 store.makerbot.com/replicator-404.html (accessed 24 February 2012).
13 3dprintingsystems.com (accessed 24 February 2012).
14 www.vam.ac.uk/content/articles/p/powerofmaking/ (accessed 24 February 2012).
15 However, we might well expect that the 'idea' of the object will also come to be shaped by the capabilities of the 3D printer (e.g. Waldby 2000).
16 Both videos are at www.coolcomponents.co.uk/catalog/plus-personal-portable-printer-p-644.html?gclid=CJbRi5WUpa4CFQ8gfAodvmJUPg (accessed 25 February 2012).
17 www.shapeways.com (accessed 28 February 2012).
18 www.shapeways.com/blog/archives/296-German-hacker-3D-prints-Dutch-police-handcuff-key.html (accessed 27 February 2012).
19 Ironically, the home is reterritorialized in distinction to the factory where 3D printers, as opposed to the plastic objects, are made. (Presumably, this will continue

to be the case until 3D printers can replicate themselves.) In any case, this suggests that to trace further the environmental implications of domestic 3D printing is to find that plastic's plasticity proliferates not only plastic objects but also the patterns of de- and re-territorialization of making and consuming, of home and workplace.

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