Automating amateurs in the 3D printing community:
connecting the dots between 'deskilling' and 'user-friendliness'

Johan Söderberg

Johan Söderberg is a post-doctoral researcher at Laboratoire Techniques, Territoires et Sociétés (LATTS) and Institut Francilien Recherche Innovation Société (IFRIS), at Paris-Est/École des Ponts, France.

ABSTRACT
In this paper a case study of an open source, home-built 3D printer called 'Rep-rap' serves as an entry point to the deskilling debate. This debate has centred on Harry Braverman's proposition that deskilling is a general trend, given the prevalence of capitalist relations of production, or, differently put, contractual employment relations. The origins of 3D printing can be traced back to numerically controlled (NC) and computerised numerically-controlled (CNC) machinery and can even be seen to incorporate 'material traces' of these. Both technologies are based on the same principle: guiding a machine tool with the help of software. NC and CNC machines were introduced in the midst of industrial conflicts and served as a touchstone in academic debates for and against the deskilling thesis during the 1970s. The open source, home-built 3D printer, in contrast, is being developed by a community of hobbyists. By definition, these hobbyists are located outside of contractual employment relations. Still, they are striving to make the 3D printer user-friendly, or, in other words, to deskill the user. Reflecting on this difference, this paper sets out to incorporate some of the critiques of the deskilling thesis in order to advance an updated, Bravermanian position on user-friendly technology.

Introduction
In this paper, I present a case study of a group of hobbyists developing an open source 3D printer.1 Previously (Söderberg, 2010a), I have described the political aspirations of the 3D printing community, rooted in a longer history of utopian engineering thinking. My focus here is on how considerations about skill and deskilling informed the design

1 My case study is based on 18 interviews with core team developers and other key promoters of the open source 3D printer. The interviews were conducted in England, Belgium, the Netherlands, Sweden, Germany, New Zealand and the United States, with three interviews conducted over the phone. Some respondents were consulted on multiple occasions. A second source of information has been the discussion forums dedicated to the project and blogs where developers share their ideas.

choices of the hobbyists. I emphasise this aspect in order to re-examine the deskilling thesis in Harry Braverman's classic Labor and Monopoly Capital. The deskilling thesis lays down the principle that, given capitalist relations of production, i.e. wage labour relations, there is a general trend towards deskilling. The relevance of my case study for revisiting this question is suggested by the fact that the 3D printer derives from computer numerical control (CNC) machinery. The principle behind both the CNC machines and the 3D printers is that a machine tool is guided by software (as opposed to being guided by a human worker). The deployment of this technology in the heavy manufacturing industry in the second half of the 20th century served as a touchstone in debates for and against the deskilling thesis. The open source 3D printer provided me with a novel entry point to an old debate that was framed by the contractual employment relationship. This framing of the issue is not surprising, considering the centrality of the workplace for core labour process theory scholars (Thompson & Smith, 2001; Thompson, 2010) Indeed, it might seem as if my chosen point of departure, a community of hobbyists, disqualifies me from drawing any conclusions about labour process theory. The relevance of my case study to labour process theory rests on recent studies showing that the labour of users, fans and audiences is being put to work by firms (Gill & Pratt, 2008; Burston, Dyer-Witheford & Hearn, 2010; Scholz, 2012). As a result, calls have been made for labour process theory to be synthesised with theories about the exploitation of free/volunteer labour in the cultural sector (Böhm & Land, 2012), and Marx's theory of value is being re-examined in the light of this trend (Fuchs, 2012). This body of empirical and theoretical work provides the background for situating the 3D printing community in a larger, historical transformation of the labour process and occupational structures. It allows me to incorporate some of the critiques of Braverman's deskilling thesis, especially the stress placed on contingency by post-structuralist writers, in an updated, Bravermanian position on user-friendly technology.

The debate over the deskilling thesis

The publication of Braverman's *Labor and Monopoly Capital* in 1974 met with a torrent of criticism issued from a variety of academic camps. Fifteen years later, Gibson Burrell summarised the debate and suggested that the book had caused such a stir because of its timing. Most of the British critics had taken aim at Braverman's generalisations. His general, theoretical claims were tested against and contrasted with the many variations which they found in their own, minutely-executed case studies at one or another workplace. Counter-tendencies and/or individual exceptions to the rule proved the deskilling thesis wrong. Evidence was not lacking to show that skills could be preserved or even increased by the introduction of new technologies (Attewell, 1987; Wood, 1982). Burrell attributes this kind of refutal to a pre-modern and empiricist intellectual tradition that protested against Braverman's modernist style of reasoning. But this was also a decade when post-modernism was in the ascendance. Labour process theory provided an iconic example of a modernist grand narrative against which the young post-modernist scholars could assert their ideas (Burrell, 1990). Scholars subscribing to this line of thought have protested that the introduction of machinery cannot be said to have resulted in a lowering of the skills of workers. Their reasoning is that the identity of the ‘worker’ is contingent on a new, ever-changing human-machine configuration. It follows that the baseline against which an increase or a decrease of skill levels could be assessed is missing. Variations on the same theme have been voiced from an oppositional camp within labour process theory (O’Doherty & Willmott, 2001), as well as from scholars coming to the debate from a neighbouring discipline, Science and Technology Studies (Grint & Woolgar, 1997; Berg, 1997; Berg, 1998). Burrell’s reappraisal draws attention to the deeper philosophical and epistemological divergences that underpinned the intellectual positions in the deskilling debate. As I do not seek to engage in the debate on this level of abstraction, I will just declare where my own sympathies lie, here. I am persuaded by recent work that defends the legitimacy and necessity of generalisations in the social sciences (Désveaux & de Fornel, 2012).

On an empirical level, the deskilling thesis was often tested against one particular technology: the application of software to guide machine tools (Zicklin, 1987). The classic work to mention here is of course David Noble’s study of the introduction of CNC machinery in manufacturing industry. Although Noble did not explicitly line up behind Braverman, his case study has been interpreted by critical reviewers as an empirical vindication of the latter’s theory (Pickering, 1995). Noble showed how CNC machinery had been promoted among scientists, policy makers and business leaders as a solution to militant trade unionism in a Cold War context. It held out the promise of doing away with the knowledge, and, subsequently, the control, which machine operators exercised on the shop-floor. By programming the movement of the machine tools in advance, managers hoped that the knowledge of blue-collar operators could be placed under the control of the white-collar engineers instead. The latter were perceived to be more trustworthy and loyal to company objectives. Ultimately, the dream was to have a fully-automated factory without any workers at all. But, as David Noble stressed in his study, the managerial dream was often frustrated. At the same moment that the introduction of CNC machinery eradicated some manual tasks, new functions were created at other levels in the production process. Furthermore, the large investments in computer equipment made managers more, rather than less, dependent on winning the consent of machine operators (Noble, 1986; Jones, 1997). Concurrently, the computer systems themselves gave rise to an ever-expanding workforce of computer programmers (Senker & Beesley, 1986; Perrolle, 1991). Already, in the 1950s, managers had begun to identify the programmers as a new source of labour problems. Like the introduction of CNC machinery into heavy industry, the creation of high-level programming languages such as FORTRAN and COBOL was hailed in the business press as a means for eradicating the need for skilled (and recalcitrant) labour in programming. Despite the many attempts to put software production under management control, programmers were remarkably successful in asserting their autonomy (Ensmenger, 2004). This suggests that, although the efforts to deskill labour might have been unsuccessful in an absolute sense, there was a continuity in the wish to pursue this goal, across the recompositions of the labour process and the transient formations of professional identities.

My reasoning comes to a full circle with the hobbyists developing an open source 3D printer. The practices and the methodologies of free software development are here applied to the design of CNC machine tools. For instance, the home-made equipment used by these hobbyists often runs software which has been taken over directly from industry (Shackleford & Proctor, 2001). It can be argued that the machine tools and the control software used by the hobbyists are 'material traces' pointing back to the (contractual, waged) machine operators in the industry. The two are internally related, in the sense that the former is the product of the desolation of the latter. This much can be extrapolated from *Labour and Monopoly Capital.* Braverman predicted that the degradation of working life (i.e. deskilling) would push people to seek refuge in hobbies and subcultural identities, and, still more intriguingly, that those activities would soon be recuperated by capital again. Prophetically, he laid down the terms for the current discussions about the exploitation of free labour in the cultural sector:

> *So enterprising is capital that even where the effort is made by one or another section of the population to find a way to nature, sport, or art through personal activity and amateur or 'underground ' innovation, these activities are rapidly incorporated into the market so far as is possible. (Braverman, 1999:193)*

Brief summary of the Rep-rap project's goals and technology

The idea of building an open source, low-cost 3D printer for home use was first formulated by Adrian Bowyer, at the time a lecturer in the engineering department at Bath university. The project was started in 2005 under the name 'Rep-rap ', an acronym for 'self-REPlicating RAPipd prototyper'. The idea of self-replication is central to the design practices of the hobbyists. Before discussing the values attached to this technical concept, a brief explanation of how the machine functions is called for. A 3D printer builds components by extruding plastic in multiple layers. There are three core components in a Rep-rap machine. Firstly, it has at least one 'material-deposition printing head' or 'extruder'. In an ordinary printer, the printing head lays down ink on sheets of paper. The Rep-rap extruder heats plastic to 210 degrees and lays it down in layer upon layer. The second key component is the mechanical structure. This is built according to the principles of a Cartesian robot, that is to say, the printing head moves along three axes and can thus be positioned in a three-dimensional space. The third component of the Rep-rap is the electronics and the software which steers the mechanical parts. Briefly put, the machine requires two kinds of software. First, there are the programs used for doing 3D modelling of the objects later to be printed. These objects have to be rendered as instructions which can be understood by the 3D printer. Then there needs to be software which tells the machine where the extruder head should move, at what speed, and so on.

The open source 3D printer produces small objects in plastic that, to most bystanders, look rather unimpressive. Most of the claims made for this technology take into account the promises that it holds for the future. The development potential is considerable because it offers a versatile approach to producing objects with complex shapes. Materials other than plastics can be printed in the same way. For instance, a modified extruder head has been developed by a hobbyist to print clay and thus make ceramic objects. Most ambitious are the experiments with printing conductive materials. They suggest the possibility that crude electric circuits can one day be printed on a home-built 3D printer. It is equally important that this manufacturing process does not involve any toxic chemicals, emit dangerous fumes or require any specialised or cumbersome industrial casing. In other words, 3D printing technology has a big potential for being adopted within the constrained conditions under which most hobbyists work.

The key technical concept behind Rep-rap is this: it aims to use the already existing bank of 3D printers to produce more 3D printers. As well as the nuts, screws and bars, i.e. general-purpose and off-the-shelf components, the machine is made up of a large number of uniquely-shaped objects which cannot be found in a hardware store. Initially, the goal of self-reproduction was pursued to solve the practical problem of getting hold of some of the parts needed to build a 3D printer. This was referred to as a problem of bootstrapping: how to print the first 3D printer. So-called 'Rep-strap ' machines were thrown together with the sole purpose of printing the required parts. Such *ad hoc* machines were built in metal, wood, bamboo and even Lego. In 2008, it was announced that the first Rep-rap machine had reproduced itself: that is to say, a 3D printer had been assembled from plastic parts printed on a 3D printer of the same kind. In fact, only about half of the parts are made from printable (plastic) parts; the rest must be bought from hardware stores. The long-term vision is to design a machine that is exclusively built from printed parts, though it remains hard to see how some key components, such as the electronics, the motors, and the extruder, could ever be created in this way. The problem of 'bad recursiveness' can most succinctly be illustrated with the proposition of printing the extruder: the extruder must be built from a material which can withstand the temperature needed to melt and extrude the material in question.

The notion of having a machine that can reproduce itself plays to old engineering tropes and creates interesting problem-solving puzzles that attract newcomers. However, as is suggested from the difficulties with bootstrapping the Rep-rap project, the concept of self-reproduction serves a purpose beyond catering to technological fantasies. It creates the conditions under which a hobbyist can build a 3D printer. On an aggregated scale, it is the hobby community that strives to reproduce itself without being reduced to an appendix of an industrial supplier. To borrow a term from the labour historian David Montgomery, the tools and practices are geared towards preserving the 'functional autonomy' (1976) of the 3D printing community. As a side-effect of designing a 3D printer capable of printing most of its own parts, the technology will be able to print many other useful and trivial consumer goods. This is how the hobbyists envisage that their technical concept will translate into broader social change. That dream can be summarised in the by-line of the Rep-rap project: 'wealth-without-money'.

Designing an alternative to mass manufacturing

The political aspirations of the hobbyists hinge on the technical concept of having a machine that can produce all the parts with which a second machine can be assembled. Crucially, a (human) user is still required to assemble the parts of the second machine. This opens up a gap between, on the one hand, the aspirations of the hobbyists, and, on the other hand, the practices surrounding the really-existing 3D printer. The possibility of making a second copy of a 3D printer is not an either/or proposition, as would be the case with copying a software program. The undertaking will be more or less difficult depending on thousand and one engineering considerations: the price and availability of the components, what tools are required to adjust the parts, the tolerances of individual parts with regard to vibration, heat and pressure, what demands are imposed by the overall mechanical construction, etc. Here, some issues that have been intensively debated include the choice between less or more advanced motors (DC motors versus stepper motors), the kind of electronics to use (single or multiple layered circuit boards), and whether or not to include expensive, hard-to-get components in the mechanical structure (such as ball bearings). At a second-order level, there are divergent opinions on whether it is acceptable to use proprietary software tools when designing the parts for the printer. Those developers who feel strongest about this put a considerable amount of effort into working around existing designs, which they feel compromise the aim and the spirit of the project. A handful of examples of sub-development projects that have been launched for this reason includes a 3D printer design without advanced bearings (Olliver, 2010-05-04), printable, plastic rods modelled after earth-quake resistant structures to give the plastic object characteristics like those it would have if it were made from metal (Higgs, 2011-11-03), and electronic boards designed in such a way that they can be manufactured by hobbyists (Hitter, 2011-09-11).

The often heated discussions over design choices arise partly from trade-offs which lie at the heart of the engineering practice itself. Should improved accuracy of the prints be given precedence over printing speed? Should the ease of assembling the machine overrule the wish to add another feature? Concurrently, those decisions are invested with ideological importance. This would be true of any engineering project, but it comes to the fore in the Rep-rap community with its publicly stated, political-economical aspirations. The technical concept of self-reproduction is the central axis around which most of the design choices gravitate. The dilemma is as follows. On the one hand, the use of more advanced components increases the accuracy of prints. When the printing quality is improved, better parts can be made for derivative machines. On the other hand, the chances of printing a greater percentage of the parts of the machine decreases the more advanced those components are (Sells, 2010-05-07; Olliver, 2010-05-04). Overarching these conflicting priorities is the imperative of maximising the diffusion of the open source 3D printer, upon which the growth of the community hinges. When this goal is made into the benchmark against which the success or failure of the project is measured, most design choices point in the direction of mass production. Concern that the project in its day-to-day practices has swayed from its long-term goal is voiced from time to time on blogs and discussion forums. It was clearly stated by a former member of the core development team who pondered over what had caused a sudden and steep increase in the number of registered users on the Rep-rap website:

We've found ourselves increasingly sliding towards designing with industrialisation in mind from the onset. Instead of designing simpler electronics that would be easy to cobble together, we have been designing boards with parts like surface-mount chips friendly to outsourcing and short production runs.

Design, for absolutely the best of reasons, has been getting more and more centralised and unified. (Clanking replicator blog, 16th January, 2009)

The undercurrent of malaise in the Rep-rap project is echoed in other hobby engineering projects that have also given themselves the task of building an alternative infrastructure, only to be pulled in by the commercial logic that they sought to undo (Söderberg, 2010b). Still, the engineering priorities and the design choices in a community-run project like Rep-rap differ greatly from those which are being pursued in the development of commercial 3D printers, where mass production is the – not always attainable – goal. This point can be illustrated with an example from Makerbot Industries. When this company was started in 2009, it had an intimate relationship with the Rep-rap community. At the time, it avowed its commitment to the values of open source, without, however, ever subscribing to the goal of self-reproduction. Subsequently, the designs of the first machines sold by Makerbot Industries were published under an open license. Users were entitled to build their own copies of the machine from the designs. This happened frequently enough that the customer services became swamped by calls from people with whom the company had no commercial relationship (Pettis, 2011-09-20). Despite the legal permission and publicly available design files, users were restricted in practice from building the 3D printer due to its mechanical construction. It included, among other things, large sections cut out from plywood. To make those parts required access to a laser cutter, a machine tool that is priced out of reach of most hobbyists. For a while, the laser cutter represented the centralised mode of production against which the Rep-rap project asserted itself as the antidote. This sentiment hardened into an ethical judgement within the 3D printing community where printed machines were praised over laser-cut machines for a mixture of technical and aesthetic reasons. This said, the meanings attributed to 'printed' versus 'laser-cut' have since been destabilised. Access to laser cutters is less of an issue nowadays, partly because of the mushrooming of collective workshops, hacklabs and hackerspaces, and partly because cheaper versions of these tools are being developed by hobbyists in other open hardware projects (two examples are Lasersaur and LAOS).

The symbiotic yet constrained relationship between the hobby community and the start-up firms can be read off from the design process, as is suggested by one minor incident. It turned out that the second-generation of the Rep-rap printer, 'Mendel ', had been designed with plastic parts which were too large to be printed on the 3D printers sold by Makerbot Industries. This was due to the smaller print size of Makerbot's 3D printers compared to other 3D printers on the market at the time. Consequently, the Makerbot 3D printer could not be used to 'bootstrap' a Mendel 3D printer. This jeopardised the Rep-rap community's opportunities to grow with an expanding market for Makerbot Industries' products. This was perceived to be enough of a threat to prompt a redesign of the Mendel printer. A new version of Mendel was released made up of parts with a size specification matching the print size of Makerbot's 3D printers (Jones, 2009-11-26). Another indication of the same phenomenon is a design uploaded to Thingiverse, a repository for 3D design files. The design in question had replaced the laser-cut parts of a Makerbot 3D printer with a jigsaw puzzle made up from smaller, printable plastic parts. Now the commercial printer could be printed without the need for a laser cutter (Makerbot blog, 4th June 2010). However, the greatest obstacle to the spread of the Rep-rap community is not due to any technical specification of the machine or the tools which it necessitates. It boils down to the skills which the machine presupposes from its builders and users.

Response to critics of the deskilling thesis

The vision of a machine capable of producing a copy of its own parts as well as printing a row of other useful goods has a historical precedent. It is a twist on the old engineering dream of designing the automated factory. In the past century-and-a-half, hopes have risen and fallen among engineers about the possibility of designing away the need for human intervention in the production process (Biggs, 1996; Turner, 2008). While some sectors, for instance the process industry, due to the nature of its operations, had already been extensively automated in the mid Twentieth Century, other sectors proved less susceptible to automation. A case in point was the production of machine tools. Machine tools tend to be sold in small volumes, which puts a limit on how far the production line can be standardised. This kind of market favours more flexible, general-purpose tools operated by all-round skilled machinists (Jones, 1997). The introduction of computer-aided machinery evoked much enthusiasm in the business community precisely because it held out the promise of overcoming the problem of small batch production. The programmable and re-programmable machine mimicked some of the flexibility of human operators, and was thus better suited to replace them. The movements of the machine tool could now be programmed in advance, first using perforated cards (NC) and later computers (CNC). It seemed as if this technology would make possible the design of a fully automated workflow without any need for human intervention on the shop floor. There were a number of motives driving investments in NC and CNC technology. It is well documented and beyond dispute, however, that union-busting rhetoric played a part in the promotion of this technology (Noble, 1986; Scranton, 2009). What remains open to question is to what extent the dreams of engineers, managers, and owners give a truthful description of how NC and CNC machines were actually deployed and what consequences this had for workers in the end.

Braverman famously stipulated that, given capitalist relations of production, i.e. wage labour relations, machinery will be designed in such a way that skilled workers can be replaced by workers requiring less training. Thus the organisational strength and bargaining position of labour can be undermined (Braverman, 1999). Support for this proposition was found in some of the empirical investigations that ensued. But Braverman's thesis was also qualified in important respects, and counter-tendencies were identified (Adler, 2007). For instance, union mobilisation and differences in political cultures were shown to have played a decisive role for the implementation of CNC machinery (Senker & Beesley, 1986; Price, 1984). It was pointed out that automation did not progress in a linear fashion that could be quantified and measured. When one task is automated, the need for decision making and skilled intervention by human operators is often shifted to another level in the production process (Wood, 1982; Wilson, 1988; Jones, 1997).

Similarly reassuring conclusions are drawn in the Socio-Technical Systems literature when the question about skill and automation resurfaces, although Braverman and Noble are rarely referred to in this discussion. A group of scholars belonging to the 'sociology of knowledge' tendency within Socio-Technical Systems engage with the related question whether computers (or artificial intelligence) will one day substitute for human thinking/knowledge. Objecting to this proposition, they have argued that knowledge is an inherently context-dependent entity. It follows that knowledge must be acquired and practiced through social interaction, something only humans are capable of (Rodrigo & Collins, 2007; Collins, 2007). The argument is compelling, although I find it wanting in one aspect. It concedes nothing to the possibility that an imperfect and partial substitution of human thinking/knowledge by computers/artificial intelligence may produce socially important outcomes. Ultimately, it is not the social question that intrigues the scholars working in the tradition of sociology of knowledge. They debate artificial intelligence in order to explore the innate characteristics and limits of human reason (Collins, 1990).

In contrast, the post-structuralist wing of Socio-Technical Systems has occasionally engaged directly with labour process theory perspectives on technology (Pickering, 1995). Like labour process theory scholars, they acknowledge the possibility that humans can be replaced by machines. This concession is made without admitting any exceptionality, analytical or normative, to the human being vis-à-vis the machine that stands to replace her. On the contrary, the critical intention in labour process theory literature has been taken to task by post-structuralist writers. Targeting the standard critique of Taylorism, they accentuate the positive outcomes that can be had from 'black-boxing' a technology. Black-boxing allows new combinations of machines and humans to emerge, and with this a greater complexity of organisation. Old identities and structures are dissolved, together with any criteria by which deskilling could be judged and condemned. Although post-structuralist Socio-Technical Systems writers are staunchly neutral and/or agnostic with regard to individual cases of deskilling, their inquiry is framed by a strongly positive evaluation of contingency as such (Grint & Woolgar, 1997; Berg, 1998; for a critique, see Tinker, 2002; Söderberg, 2010a).

Closely following the template outlined above, Stefano de Paoli and Christiano Storni have mobilised a case study of 'Arduino' against the deskilling thesis. Arduino is an electronic board developed under an open license and supported by a large community of users. The case study has a bearing on the Rep-rap project, because derivative versions of the Arduino board are used in many open source 3D printers. The authors focus on a modification of Arduino which spares users from having to solder discrete components onto the electronic board. Newcomers are easily daunted by soldering. The design modification of Arduino lowered the threshold for experimenting with the technology, thus allowing more people to join the project. The authors take this lesson as a vindication of the claim that black-boxing or deskilling can have beneficial outcomes as well as negative ones (de Paoli & Storni, 2011). This answer is correct but misleading, because the question has been stated in overly abstract terms. What de Paoli and Storni take for a conclusion is merely the starting point; the next step is to situate deskilling processes historically, for instance in relation to transformations of occupational structures in society. In the example of the Arduino hobby community, newcomers encounter a more user-friendly electronic board in a setting framed by non-remunerated, volunteer contributions, as opposed to a setting framed by contractual employment relations. Consequently, there is no employer against whom the soldering skills could have served as leverage in a bargaining situation. It follows that users of Arduino experience deskilling processes differently from how they were experienced by the blue-collar workers studied in the labour process theory literature. The failure of de Paoli and Storni to reflect on this difference considerably weakens their case against the deskilling thesis.

My point above resonates with David Harvey's intervention in the Braverman debate. He finds that many critics of labour process theory miss their target because they are taking aim at deskilling in an absolute sense. What is then overlooked is how skill/deskilling plays into power relations and worker autonomy at a given, historical moment. It is not skill *per se* that is at stake, but skill as a focal node in the tug-of-war between employees and employers. This qualification voids a common objection, echoed both by sympathetic commentators like Richard Price and more strident opponents like Stephen Wood. Addressing Braverman, they insist that technology does not lead to the destruction of skill but rather to its recomposition, leaving workers with viable bases from which they retain or create new forms of protection in the labour process. The statement is correct but sidelines the real issue, namely that recompositions of the labour process tend to be unleashed where workers are organised, skilled and well paid. In thus defending the deskilling thesis on the grounds that it is a partial, situated statement, have I not unwittingly shown the critics to be right in their objection to the claim that there is a general, cumulative trend of deskilling? David Harvey argues that a historical trend can be hypothesised, although with an important qualification. The trend does not consist so much in a degradation of skill as in a generalisation of skill. Crucially, it does not matter if generalisation is achieved through an upgrading or downgrading of skills. What matter is that tasks are made interchangeable, so that the reserve army of labour can be expanded and labour costs cheapened. Because critics of labour process theory tend to absolutise skill levels, they fail to see that the counter-trends that they are identifying could be consistent with Braverman's line of reasoning (Harvey, 2006:119; Choi, Leiter & Tomaskovic-Devey, 2008).

Deskilling the user of 3D printers

The empowerment of users and the spread of 'computer literacy' to the public is an example of how skill is being generalised. This is how the 3D printing hobby community can be situated in the transformations of the labour process and occupational structures. CNC machines, previously requiring many years of instruction and practice to operate successfully, can now be run by hobbyists. Indeed, to the developers in the Rep-rap community deskilling or black-boxing is vaunted as the chief advantage of their 3D printer over older manufacturing techniques. The following text was posted on the discussion forum of the Reprap website by one of the core members of the project:

RepRap is hardly the first device that can manufacture itself. Machine tools (particularly the lathe) have been able to do this for a long time. (And if you take a more diffuse view, a properly-equipped workshop could replicate itself as well). However, a lathe can only replicate itself in the hands of a skilled operator, and it's still quite a bit of work. An untrained ten-year-old can build a RepRap using another RepRap, in a week or so, just by hitting print and leaving the machine alone most of the time. (General discussion forum, 18 May, 2007).

The final sentence gives a description of actually existing 3D printers as fanciful as any managerial dream about the automated factory. The truth is that Rep-rap machines are far from standardised. To get a machine to work reliably with consistent results is not a trivial task. The user must be familiar with the idiosyncrasies of that particular machine. Such knowledge is typically acquired in the process of assembling the same machine. And the task of assembling a Rep-rap 3D printer can be very demanding (Nipe, 23, December 2009). It requires knowledge about soldering, mechanics, electronics, and, on top of that, some programming skills. The kits sold by firms are less demanding to cobble together. This discrepancy between the actual and perceived skill requirements voids the advantage which the Rep-rap project claims for itself compared to commercial 'Rep-straps '. The legal permission to build a 3D printer specified in the open license, the availability of the design files on the Internet, the redesign of the Mendel Rep-rap printer to reduce the required print-size for making parts for it, together with all the other considerations that have been taken into account in the dissemination of this tool, rely crucially on the restricted know-how of the average user. It is against this background that one should understand the wish of the hobbyists to design an open source 3D printer so that even a ten-year old could use it. The risk is otherwise that the open source 3D printer will be sidelined by more user-friendly, but closed and commercial, 3D printers.

What is at stake, in other words, is the ability of the hobbyist community to assert itself and its political vision in a field increasingly dominated by commercial interests. The hobbyists pursue automation with as much zeal as the blue-collar workers fought against it. In both instances, tools and skill are central to preserving the 'functional autonomy' of the collective *vis-à-vis* an external, hostile force. The difference is, of course, that the significance of automation has been diametrically reversed. A token of this is the opposite values given to the two terms 'deskilling' and 'user-friendliness'. In saying this, I acknowledge that the post-structuralist critics of labour process theory are right in stressing contingency. It could be said that the introduction of CNC machines into heavy industry, later to metamorphose into 3D printers, rendered contingent the identity of blue-collar workers while giving rise to a new human-machine configuration: that of the (unemployed) amateur or underground inventor. It is because Braverman was aware of the centrality of contingency that he refused to comply with the expectation of basing his analysis on a definition of the working class:

The term 'working class', properly understood, never precisely delineated a specified body of people, but was rather an expression for an ongoing social process. [...] We are dealing not with the static terms of an algebraic equation, which

> *requires only that quantities be filled in, but with a dynamic process the mark of which is the transformation of sectors of the population." (Braverman, 1999:7)*

The difference between Braverman and his post-structuralist critics is that the latter are unable, due to their philosophical tenets, to situate the ruptures of meaning and identity formation that they profess in a larger historical transformation (of the capitalist labour process and occupational structures, among other things).

Conclusions

The open source 3D printer represents a material trace pointing back to CNC machinery. But the two technologies were developed under very different, historical conditions. CNC machinery was introduced in a setting framed by contractual employment relations, that is to say in a relationship defined by structured antagonism between employee and employer. In contrast, the hobbyists in the Rep-rap community contribute to an open source engineering project without being either coerced or remunerated (the two, of course, being intimately related). The connection I am trying to establish between these two technologies, together with contiguous meanings and practices, hinges on recent work on free labour in the cultural sector. A growing body of studies has shown that volunteer contributions by users, fans and audiences are becoming structural to the functioning of the culture and high-tech industries. What initially appears to be a voluntarily-entered activity takes on a more coercive character when the community is subsumed under the logic of value production (Fuchs & Trottier, 2013). The case of Makerbot Industries is suggestive of how the 3D printing community has been used to procure ideas and innovations for start-up firms and venture capitalists. The stakes are soaring, as is suggested by a report predicting that the worldwide market for industrial- and consumer-grade 3D printers will grow to $3.1 billion by 2016 (Wohlers, 2011).

These observations provide a backdrop for situating the 3D printing community in a larger historical transformation of the labour process and occupational structures. Although my point of departure for reflecting on labour process theory was external to contractual (waged) employment relations, the community has rapidly been subsumed under market relations and more informal means of making a living. That said, this was not the case when the open source 3D printer was first conceived. It can therefore be taken as a vantage point for reflecting on one of the preconditions for the deskilling thesis: namely, the prevalence of capitalist relations of production, or, differently put, wage labour relations. According to Braverman, the detrimental effects of machinery derive exclusively from the social relations under which the technology has been developed and put to use. By definition, the hobbyists are 'outside' the contractual employment relation. It goes without saying that the hobbyists are still making a living within the confines of capitalism; but their professional identities, whether as students, retired engineers, or well-off part-timers in the high-tech sector, are peripheral to their contributions in the hobby community. The hobbyists have enjoyed a space of manoeuvre, however limited, that makes it possible to explore the utopian promises of automation, already recognised by Harry Braverman:

The re-unified process in which the execution of all the steps is built into the working mechanism of a single machine would seem now to render it suitable for a collective of associated producers, none of whom need spend all of their lives at any single function and all of whom can participate in the engineering, design, improvement, repair and operation of these ever more productive machines. (Braverman, 1999:320).

REFERENCES

Attewell, P. (1987) 'The Deskilling Controversy', *Work and Occupations* 14:323-346.
Bain, P., A. Watson, G. Mulvey, P. Taylor, P. & G. Gall (2002) 'Taylorism, targets and the pursuit of quantity and quality by call centre management', *New Technology, Work and Employment,* 17 (3):170-185.
Banks, J & M. Deuze (2009) 'Co-creative labour', *International Journal of Cultural Studies*, 12 (5):419-431.
Barett, R. (2005) 'Managing the software development labour process: Direct control, time and technical autonomy', R. Barett, (ed), *Management, labour process and software development,* London: Routledge:76-99.
Berg, M. (1998) 'The politics of technology: On bringing social theory into technological design', *Science, Technology & Human Values,* 23(4):456-490.
Biggs, L. (1996) *The rational factory: architecture, technology, and work in America's age of mass production*, Baltimore: The Johns Hopkins University Press.
Blok, A. & G. Downey, G. (eds) (2004) *Uncovering labour in information revolutions, 1750-2000,* London: Cambridge University Press.
Braverman, H. (1999) *Labor and monopoly capital: The degradation of work in the twentieth century*, New York: Monthly Review Press.
Burston, J., N. Dyer-Witheford & A. Hearn (2010) 'Digital labour', Special issue, *Ephemera* 10 (3-4):214-539.
Böhm, S. & C. Land (2012) 'The new "hidden abode": Reflections on value and labour in the new economy', *Sociological Review,* 60 (2):217-240.
Callaghan, G. & P. Thompson (2001) 'Edwards revisited: Technological control and call centres', *Economic and Industrial Democracy,* 22(1):13-37.
Choi, S., J. Leiter. & D. Tomaskovic-Devey (2008) 'Contingent Autonomy: Technology, Bureaucracy, and Relative Power in the Labor Process', *Work and Occupations*, 35:422-455.
Collins, H. (1990) *Artificial experts: Social knowledge and intelligent machines*, Cambridge, Mass.: MIT Press.
Collins, H. (2007) 'Bicycling on the moon: Collective tacit knowledge and somic-limit tacit knowledge', *Organization Studies,* 28(2):257-262.
Daryl, H. (2003) 'The Cost of Inventiveness: Labor's Struggle with Management's Machine', *Technology and Culture,* 44 (1):102-113.
de Bruijn, E. (2010) *On the viability of the open source development model for the design of physical objects: Lessons learned from the RepRap project*, Master's thesis. Netherlands: University of Tilburg.
Désveaux, E. & M. de Fornel (2012) *Faire des sciences sociales – Généraliser*, Paris: EHESS.
de Paoli, S. (2011) 'Produsage in hybrid networks: Sociotechnical skills in the case of Arduino', *New Review of Hypermedia and Multimedia*,17(1):31-52.
Ensmenger, N. (2004) 'Letting the "computer" take over: Technology and the politics of organizational transformation', A. Blok & G. Downey (eds*), Uncovering labour in information revolutions, 1750-2000,* London: Cambridge University Press:153-180.
Friedman, A. (1977) *Industry and labour: Class struggle at work and monopoly capitalism*, London: Macmillan.

Friedman, A. (2004) 'Strawmanning and labour process analysis', *Sociology*, 38(3):573-591.
Fuchs, C. & D. Trottier, D. (2013) 'The Internet as surveilled workplayplace and factory', S. Gutwirth,R. Leenes, P. de Hert & Y. Poullet (eds), *European data protection. Coming of age*,. Dordrecht: Springer:33-57
Fuchs, C. (2012) 'Dallas Smythe today: the audience commodity, the digital labour debate, Marxist political economy and critical theory. Prolegomena to a digital labour theory of value', *TripleC*, 10 (2):692-740.
Gershenfeld, N. (2005) *Fab: Personal fabrication, fab labs, and the factory in your computer,* New York: Basic Books.
Gill, R. & A. Pratt (2008) 'In the social factory?: Immaterial labour, precariousness and cultural work', *Theory, Culture and Society*, 25 (7-8)1-30.
Grint, K. & S. Woolgar (1997) *The Machine at Work –Technology, Work and Organisation*, Cambridge: Polity Press.
Harvey, D. (2006) *The limits to capital*, London: Verso.
Jamison, F. (1991) *Postmodernism, or, the cultural logic of late capitalism*, Durham: Duke Press.
Jones, B. (1997) *Forcing the factory of the future: Cybernation and societal institutions*, Cambridge: Cambridge University Press.
Jones, S. (1982) 'The organization of work. A historical dimension', *Journal of Economic Behaviour and Organization*, 3 (2-3):117-137.
Kraft, P. (1977) *Programmers and managers: The routinization of computer programming in the United States*, Heidelberg: Springer-Verlag.
Montgomery, D. (1976) 'Workers' control of machine production in the nineteenth century', *Labor History*, 17 (4):485-509.
Noble, D. (1986*) Forces of production: A social history of industrial automation*, New York: Oxford University Press.
Noble, D. (1977) *America by design: Science, Technology, and the rise of corporate capitalism*, Oxford: Oxford University Press.
O'Doherty D. & H. Willmott (2001) 'Debating Labour Process Theory: The Issue of Subjectivity and the Relevance of Poststructuralism', *Sociology*, 35(2):457-476.
Olliver, V. (2005) *Construction of Rapid Prototyping Testbeds Using Meccano.* Accessed on April, 30, 2013: from http://reprap.org.
Parker, M. (1999) 'Capitalism, Subjectivity and Ethics: Debating Labour Process Analysis', *Organization Studies*, 20 (1):25-45.
Pickering, A. (1995) 'The mangle of practice: Time, agency and science', Chicago: University of Chicago Press.
Perens, B. (2008) 'RepRap vs. Reality', *Technocrat.* Accessed on April, 30, 2013 from: http://technocrat.net/d/2008/6/5/42592/,
Perolle, J. (1991) 'Expert enhancement and replacement in computerised mental labor', *Science, Technology and Human Values*, 16 (2):195-207.
Postigo, H. (2004) 'Emerging sources of labor on the Internet: The case of America Online volunteers', A. Blok & G. (eds), *Uncovering labour in information revolutions, 1750-2000*, London: Cambridge University Press:205-223.
Price, R. (1984) 'Structures of subordination in the labour movement in nineteenth-century British industry', P. Thane, G. Crossick & R. Floud (eds), *The Power of the past. Essays for Eric Hobsbawm,* Cambridge: Cambridge University Press:119-142.
Rabeharisoa, V. & M. Callon (2003) 'Research "in the wild" and the shaping of new social identities', *Technology in Society*, 25(2):193-204.
Ribeiro, R. & H. Collins (2007) 'The bread-making machine: Tacit knowledge and two types of action', *Organization Studies,* 28(9):1417-1433.
Scranton, P. (2009) 'The shows and the flows: materials, markets, and innovation in the US machine tool industry, 1945–1965', *History and Technology*, 25(3):257-304.
Senker, P. & M. Beesley (1986) 'The need for skills in the factory of the future', *New Technology, Work and Employment*, 1(1)9-17.
Shackleford, W. & F. Proctor (2001) *Use of open source distribution for a machine tool controller,*

Conference paper, vol. 4191:19–30, Accessed on April 30, 2013 from: http://www.isd.mel.nist.gov/documents/shackleford/4191_05.pdf.
Scholz, T. (ed) (2012) *Digital labour: The Internet as playground and factory*, New York: Routledge.
Stallman, R. (2002) The GNU project and free software. In G. Joshua (Ed.) Free Software, Free Society: Selected Essays of Richard M. Stallman. Boston, MA.: GNU Press.
Söderberg, J. (2010a) 'Misuser Inventions and the Invention of the Misuser: Hackers, Crackers and Filesharers', *Science as Culture,* 19(2):151-179.
Söderberg, J. (2010b) 'Reconstructivism versus critical theory: Alternative perspectives on activism and institutional entrepreneurship in the Czech wireless community', *Social Epistemology* 24(4):239-262.
Terranova, T. (2000) 'Free labour: Producing culture for the digital economy', *Social Text* 18(2):33-58.
Thompson, P. & C. Smith (2001) 'Follow the redbrick road: Reflections on pathways in and out of the labour process debate', *International Studies of Management and Organization*, 30(4):40-67.
Thompson, P. (2010) 'The capitalist labour process: Concepts and connections', *Capital and Class,* 34(1):7-14.
Tinker, T. (2002) 'Spectres of Marx and Braverman in the twilight of postmodernist labour process research', *Work Employment Society*, 16(2):251-281.
Turner, F. (2008) 'Romantic automatism: art, technology, and collaborative labor in cold war America', *Journal of Visual Culture*, 7(1):5-26.
Wardell, M. (1990) 'Labour and labour process', D. Knights & H. Willmott (eds) *Labour Process Theory,* London: Macmillan:153-176.
Wilson, F. (1988) 'Computer numerical control and constraint'. D. Knights & H. Willmott (eds) *Labour Process Theory,* London: Macmillan:66-90.
WOHLERS (2011) *Wohlers Report 2011*.
Wood, S. (ed) (1982) *The degradation of work?: Skill, deskilling, and the labour process,* London: Hutchinson.
Wood, S. (1987) 'The deskilling debate, new technology, and work organization', *Acta Sociologica,* 30(1):3-24.
Zicklin, G. (1987) 'Numerical Control Machining and the Issue of Deskilling: An Empirical View', *Work and Occupations,* 14:452-466.

INTERVIEWS

Adrian Bowyer, 2009-11-24. Initiator of the Rep-rap project, Bath, UK.
Batist Leman, 2009-11-12. Promoter of Rep-rap in Flanders. Initiator of a hackerspace in Ghent, Belgium.
Bre Pettis, 2011-09-20. One of three founders of Makerbot Industries, the second oldest company selling Rep-rap derivatives. New York, USA
Chris Palmer, aka Nophead, 2010-03-17. Made key contributions to the extruder head, among other things. Holds the record in selling Rep-rap printed parts. Manchester, England.
Ed Sells, 2010-05-07. Former PhD student of Adrian Bowyer at Bath. Principal architect of the Mendel Rep-rap design, Auckland, New Zeeland.
Erik de Bruijn, 2009-11-11. Core developer of Rep-rap and founder of the firm Ultimaker, Eindhoven, Netherlands.
Forrest Higgs, 2011-11-03. Former core developer of Rep-rap, initiator of Tommelise 3D printer. phone interview.
Gustav Nipe, 2009-12-23. Promoter of Rep-rap in Sweden. Initiator of the Swedish Pirate Party's 'Pirate factory ', Lund, Sweden.
Ian Adkins & Iain Major, 2009-11-26. Founders of Bites-from-Bytes, the first firm based on selling Rep-rap derivatives, Clevedon, UK.
Josef Prusa, 2011-09-19. Principal architect of the Prusa Rep-rap design, New York, USA.
Lambert Anders, 2011-09-19. One of two founders of Techzone, New York, USA.
Lawrence Kincheloe, 2009-11-10. Promoter of open manufacturing. phone interview.
Markus Hitter, aka Traumflug, 2011-09-11. Maintainer of Gen 7 electronics. phone interview.

Nick & Bruce Wattendorf, 2011-09-18. Promoters of Rep-rap in the New England area, built the third Rep-rap Darwin machine in the world, New York, USA.
Rhys Jones, 2009-11-26. PhD student of Adrian Bowyer at Bath. Develops multiple materials for printing. Bath, UK.
Vik Olliver, 2010-05-04. Built the first proof-of-concept of Rep-rap, among many other things. Auckland, New Zeeland.

INTERNET RESOURCES CITED IN THE ARTICLE

Hydraraptor http://hydraraptor.blogspot.com/
Clanking replicator blog (pdf available here) http://garyhodgson.com/reprap/reprap-developer-bookshelf/
Open 3DP/University of Washington http://open3dp.me.washington.edu/2011/02/prusa-mendel-and-the-clonedels/

ACKNOWLEDGEMENTS:

The case study on which this paper is based was jointly funded by Learning and Media Technology Studies and Centre of Globalisation and Development, both located at the University of Göteborg. The article has been improved thanks to feedback from Benoit Lelong, Carl Cassegård, Bertil Rolandsson, Magnus Eriksson, and my collegues at LATTS.