Article

Science, Technology, & Human Values
38(6) 773-800

DOI: 10.1177/0162243913493676
sthv.sagepub.com

Peer Production and Desktop Manufacturing: The Case of the Helix_T Wind Turbine Project

Vasilis Kostakis[1], Michail Fountouklis[2], and Wolfgang Drechsler[1]

Abstract

Through the case of the Helix_T wind turbine project, this article sets out to argue two points: first, on a theoretical level, that Commons-based peer production, in conjunction with the emerging technological capabilities of three-dimensional printing, can also produce promising hardware, globally designed and locally produced. Second, the Commons-oriented wind turbine examined here is also meant to practically contribute to the quest for novel solutions to the timely problem of the need for (autonomous) renewable sources of energy, more in the sense of a development process than as a ready-to-apply solution. We demonstrate that it is possible for someone with partial initial knowledge to initiate a similar, complex project based on an interesting idea, and to succeed in implementing it through collaboration

---

[1] Tallinn University of Technology, Tallinn, Estonia
[2] P2P Lab, Ioannina, Greece

Corresponding Author:
Vasilis Kostakis, Tallinn University of Technology, Akadeemia tee 3, Tallinn 12618, Estonia.
Email: kostakis.b@gmail.com

with Commons-oriented communities, while using peer-produced products and tools. Given the trends and trajectories both of the current information-based paradigm and the problems of the predominant industrial modes of production with all the collateral damage they entail, this may be considered a positive message indeed.

Keywords
futures, alternative life forms, space/place/scale dynamics, politics, power, governance, other, environmental practices

Introduction

There have been debates as to whether an information and/or network society really exists, as well as about the degree of technological determinism that is required to "grasp the processes of history in which we are entangled" (Heilbroner 1994, 78). Authors such as Webster (2002a, 2002b) have argued that the idea of an information society cannot be sustained. They highlight the continuities of the current age with former social and economic arrangements and claim that informational developments have been considerably influenced by familiar constraints and priorities (H. Schiller 1981, 1984, 1996; D. Schiller 1999; Webster 2002a, 2002b). Kumar (1995, 154) postulates that the information explosion "has not produced a radical shift in the way industrial societies are organized, or in the direction in which they have been moving. The imperatives of profit, power and control seem as predominant now as they have ever been in the history of capitalist industrialism." In addition, Berry (2008, 369), in his critique of the concept of network society, argues that scholars such as Benkler (2006) fall into a trap when putting a strong emphasis on the network forms of organization and production and failing to recognize "the extent to which, if they are indeed so wealth-generating, they will be co-opted into mainstream 'industrial' ways of production."

The counterposition, the one criticized by the scholars cited above, maintains (Castells 2000, 2003; Benkler 2006; Bauwens 2005; Perez 2002) that increasing number of people are now able to manage their political, social, and productive lives through a variety of interdependent networks enabled by the participatory nature of contemporary information and communication technology (ICT). These trends contribute to the formation of a social order increasingly based on meaningful cooperation (Benkler 2006; Bauwens 2005; Kostakis 2013). This is the basis of the "popular" assumption during the last decade or two that the world has been shifting toward information- and networked-based structures, with information production in the limelight (Castells 2000, 2003). In the context of Carlota Perez' influential neo-Schumpeterian theory of techno-economic paradigm shifts (TEPS), during the installation period of the current techno-economic paradigm, based on and led by ICT (Perez 1983, 2002, 2007, 2009; Drechsler, Kattel, and Reinert 2009), two parallel shifts have taken place: not only did the economically most advanced societies move toward an information-based economy but also the declining costs of ICT made them available to a much wider part of the world population (see also Benkler 2006).

The take of this article is integrative, trying to highlight the potential of new modes of social production which are immanent in (modern) capitalism (Sombart [1928] 1987) but, in the long term, might transcend the dominant system (Kostakis 2013). That is why we chose to develop our narrative within a framework based on the work of scholars, specifically Castells (2000, 2003), Benkler (2006), Bauwens (2005), and Perez (2002), who understand capitalism as a "creative destruction" process, examining the dynamics of new modes of production which on one hand create new forms of capitalism while on the other may point out how that new form can be overcome (Bauwens 2005; Kostakis 2013). We try to avoid—as they do—the hard technological determinism along the lines of Marx's and Smith's (1994, xiv) redefinition as referring "to the human tendency to create a society that invests technologies with enough power to drive history."

Through the case of the Helix_T project and prominent Commons-based projects such as free/open source software (FOSS) or Wikipedia, we attempt to show that there is an emergence of a technology shaped by human factors which could then shape the environment under which humans live and work, creating what Benkler (2006, 31) calls new "technological-economic feasibility spaces" for social practice. These feasibility spaces include different social and economic arrangements where profit, power, and control do not seem as predominant as they have been in the history of modern capitalism.

Benkler (2006) has argued that from this new communicational, interconnected, virtual environment, a new social productive model is emerging which is different from the industrial one. He describes this new model, exemplified by the FOSS projects or the online encyclopedia Wikipedia, as Commons-Based Peer Production (CBPP), which reduces the value of proprietary strategies, making public, shared information more important, and which allows for large-scale, cooperative, voluntary information production efforts. Therefore, CBPP, in this context, could be considered a new mode of production that has been enabled through Internet-based coordination where decisions arise from the free engagement and cooperation of the people, who coalesce to create common value without recourse to monetary compensation as key motivating factor (Bauwens 2005; Orsi 2009).

Since in CBPP there is something of an innate necessity for almost zero marginal costs for reproduction, one may argue that this has kept it within the confines of information production: "electrons are cheap, but atoms are expensive," as Ackermann (2009, 210-11) states. This article argues that the productive practices first observed in FOSS projects can be expanded into hardware and material production and therefore creates further evidence that CBPP has the potential, in conjunction with the emerging desktop manufacturing technologies, to supplant older, industrial, centralized modes of material production.

What happens if the costs of the production of physical goods decline considerably due to the development of desktop manufacturing machinery in the fashion of cheap distributed ICT? It is a fact that advancements in integrated circuits' transistor capacity and speed have rapidly lowered computer prices (Tuomi 2002). So what would be the consequences if the desktop manufacturing machinery, facilitated by a continuous stream of innovation and an aggressive pricing policy, as happened in semiconductor industry (Tuomi 2002), becomes affordable, that is, if owing a three-dimensional (3D) printer would not cost considerably more than owing a personal computer? Could a synergy between low-cost ICT and desktop manufacturing technologies offer chances at least for realistic experimentation to approach innovative solutions to timely problems, such as the need for renewable sources of energy (Rifkin 2011; Patel 2005)? And if so, what would such a machinery and production process look like, and are there some examples or at least tentative prototypes that might make this a realistic option? In response to these questions, we aim to shed light on the potential of the conjunction of CBPP products and processes and the emerging technological capabilities of 3D printing through the case study of the Helix_T wind turbine project.

This article begins with a brief outline of the theoretical background concerning some fundamental characteristics of CBPP as well as the potential of its convergence with desktop manufacturing, in relation to current trends of energy production. Next, we present the case study of the Helix_T wind turbine, which was a project run by one of the article's authors, Michail Fountouklis. We then discuss the results in relation to the potential of the CBPP desktop manufacturing synergy, concluding with suggestions for future research.

Theoretical Background

Some Fundamental Characteristics of CBPP

According to Benkler (2006), CBPP is a more productive system for information than the market-based or the "bureaucratic-state" systems. It produces social well-being because it is based on people's intrinsic positive motivations (for instance, the need to create, learn, and communicate) and synergetic cooperation among participants and users (Benkler 2006; Hertel, Niedner, and Herrmann 2003; Lakhani and Wolf 2005). As Hertel, Niedner, and Herrmann (2003, 1174) mentioned in their study of the incentives of 141 Linux kernel community participants, the former were driven "by similar motives as voluntary action within social movements such as the civil rights movement, the labor movement, or the peace movement." Benkler makes two intriguing economic observations which challenge some "eternal truths" of the so-called *Standard Textbook Economics* (STE) model. Commons-based projects fundamentally challenge the STE assumption—today often theoretically softened but practically still ubiquitous—that in economic production, the human being solely seeks profit maximization. Volunteers contribute to information production projects, gaining knowledge, experience, and reputation and communicating with each other, motivated by intrinsically positive incentives. This does not mean that the monetary motive is totally absent; however, it is relegated to being a peripheral concept only (Benkler 2006).

The second challenge is directed against the conventional wisdom that, in Benkler's (2006, 463) words, "we have only two basic free transactional forms—property-based markets and hierarchically organized firms." CBPP can be considered a third way, and it should not be treated as an exception but rather as a widespread phenomenon, which, however, is not currently counted in the economic census (Benkler 2006). In STE terms, what is happening in CBPP can be considered, as Bauwens (2005) maintains, "only in the sense that individuals are free to contribute, or take what they need, following their individual inclinations, with a [sic] invisible hand bringing it all together, but without any monetary mechanism." Hence, in contrast to markets, in CBPP the allocation of resources is not done through a market-pricing mechanism, but hybrid modes of governance are employed, and what is generated is not profit, but use value, that is, a Commons (Bauwens 2005).

Following Bauwens (2005, 2009), CBPP is based on practices that stand in contrast to those of the market-based business firm. More specifically, CBPP is opposed to industrial firms' hierarchical control and authority and is rather based on communal validation and negotiated coordination (see, for instance, Dafermos' (2012) study on the Free BSD project's collectivist and consensus-oriented governance system) as quality control is community-driven and conflicts are solved through an ongoing mediated dialogue (e.g., in Wikipedia, the dialogue takes place in the discussion page of each article). However, in cases such as in the internal battle between inclusionists and deletionists, Wikipedia's lack of a clearly defined constitution led a small number of participants to create rules in conflict with others: persistent, well-organized minorities adroitly handled their opponents seriously challenging the sustainability of the project (Kostakis 2010). Thus, it has to be stressed that when abundance is replaced by scarcity (as happened in Wikipedia when deletionists demanded a strict content control), power structures emerge because CBPP mechanisms cannot function well (Kostakis 2010). Moreover, investigating prominent CBPP projects, O'Neil (2009) analyzed the tensions generated by the distribution of authority and showed that it is important to discuss openly how power and authority actually work in CBPP in order to be able to arrange differently. His proposal is that leaders must support maximum autonomy for participants toward a more egalitarian situation. Of course, a special characteristic of CBPP is that if these benevolent dictators (Kostakis 2010) abuse their power, their leadership becomes malicious and a substantial exodus of community members often happens. These members, however, due to the low marginal costs of information, are free to start their own new project, using the already Commons-based peer produced information if they wish.

Further, CBPP is not driven by the for-profit orientation that defines market projects, as peer projects have a for-benefit orientation, creating use value for their communities. This does not mean that in CBPP projects, the profit motive is totally absent, but rather, that incentives such as learning, communication, and experience come to the fore (as applies in the case of Helix_T project)—and that is actually how the human person actually operates, rather than the imagined *homo oeconomicus* of STE. Besides, Hess' (2005, 515) "private-sector symbiosis" hypothesis outlines that the emphasis on technology and product innovation can lead "to the articulation of social movements goals with those of inventors, entrepreneurs, and industrial reformers" (2005, 516). Therefore, "a cooperative relationship emerges between advocacy organizations that support the alternative technologies/products and private sector firms that develop and market alternative technologies" (Hess 2005, 516).

For example, the case of Linux and IBM comes in accordance with Hess' argument for the private sector symbiosis and subsequent incorporation and transformation of the technologies which may provoke, though, an object conflict. "As the technological/product field undergoes diversification," Hess (2005, 515) writes, object conflicts "erupt over a range of design possibilities, from those advocated by the more social movement-oriented organizations to those advocated by the established industries." It can be claimed that an object conflict is taking place concerning the Makerbot's Replication 2 3D printer which is partly closed source and this may lead, say, to the loss of Makerbot community (Giseburt 2012). The core technologies remain open source, according to Makerbot cofounder Bre Pettis; but on the other hand, because open source hardware entails considerable marginal costs and some kind of entrance barriers, open hardware businesses must be careful about what they open source and what not (Pettis 2012).

Instead of the division of labor in CBPP, a distribution of modular tasks takes place with anyone able to contribute to any module, while the threshold for participation is as low as possible. And it is opposed to the rivalry (scarcity of goods) through which market profit is generated, as sharing the created goods does not diminish the value of the good, but actually enhances it (Bauwens 2005; Benkler 2006). To this, one might add that CBPP is facilitated by free, unconstrained, and creative cooperation of communities, which lowers the legal restrictive barriers to such an exchange, inventing new institutionalized ways of sharing, such as the Creative Commons, the Berkeley Software Distribution, or the General Public Licenses (Kostakis 2011a, 2011b, 2012). In terms of property, the Commons is an idea different from state (*public*) property, where the state manages a certain resource on behalf of the people, and from private property, where a private entity excludes the common use of it (Kostakis 2009, 2011b, 2012).

It is, however, important to highlight that the contributors of CBPP projects do have interests and rights concerning their work and are interested in protecting their intellectual property (O'Mahony 2003). Thus, the Commons-oriented approach to property "does not assert that sharing is an ethical absolute" (after all everyone is, or should be, free to choose what type of license they will adopt), but tries to manage to balance the rights of innovators with the rights of the public (O'Mahony 2003; von Hippel and von Krogh 2003).

It becomes obvious that what sets CBPP apart from the proprietary-based mode of production—the "industrial one" (Benkler 2006)—is its modes of governance (consensus-oriented governance mechanisms) and of property (communal shareholding), whose foundation stones are the abundance of resources, openness, and the power of meaningful human cooperation. These are the very characteristics of CBPP that provide the capacity to deliver genuinely innovative, remarkable results (thus contesting allegations of low quality: see only Keen 2007; Lanier 2010), such as the Apache web server, Mozilla Firefox browser, Linux kernel, BIND (the most widely used DNS software), and Sendmail (router of the majority of e-mail).

Of course, beyond the great potential of CBPP, there may well be numerous obstacles, theoretical and practical problems, and negative side effects. However, taken in this idealized context, CBPP arguably carries some aspects which create a political economy where economic efficiency, profit, and competitiveness cease to be the sole guiding stars (Moore and Karatzogianni 2009), while civil society attains a more important role, bringing (back) the notion of cooperation into the very heart of the economy (Orsi 2009).

The Convergence of CBPP and 3D Printing and the Small-scale Energy Producers

Rifkin (2011) observes the emergence of small-scale energy producers and cooperatives, which could generate their own renewable energies in their places and trade or share surpluses in info-energy Commons. For example, see initiatives such as the Nordic Folkecenter (2012) from Denmark (Mercier and Jean 2006) or Barefoot College (2012) in India, which are developing small-scale energy production practices. The latter focuses specifically on providing basic services and solutions to the problems of rural communities, with the objective of making them self-sufficient and sustainable. CBPP approaches to the development of small-scale, autonomous energy production are also followed by open design communities such as the nonprofit organization Onawi (2012) from England or Nea Guinea (2012) from Greece.

Carlota Perez's TEPS theory (Perez 1983, 2002, 2009) would predict such a shift from giant fossil fuel–based energy companies to small producers (Rifkin 2011), because the traditional, highly centralized mode of energy production would have to be modernized (in the sense of updated or brought to accommodate the special characteristics of the current ICT-based paradigm). A convergence of CBPP practices in designing, sharing, and improving blueprints, along with desktop manufacturing capabilities, could be such a modernization and thus would underscore the general importance of autonomous energy production. Desktop manufacturing could arguably allow for autonomous and decentralized design and manufacturing of useful tools and equipment for producing energy.

Rapid prototyping machines or “3D printing”—actually a subset of additive manufacturing—is, in short, the process of joining material, layer by layer, to make objects from 3D model data (usually created by a computer-aided design software or a scan of an existing object), in contrast to subtractive manufacturing technologies (American Society for Testing and Materials 2010). This technological capability, now more than thirty years old, is called *rapid* because one-offs could be made more easily and quickly than by the conventional numerically controlled machines and it was called *prototyping* because it was too slow and expensive to be used for production (Bradshaw, Bowyer, and Haufe 2010; Campbell et al. 2011). For example, an architect could print in 3D the design of a building or an automobile engineer could print a prototype of a part from the car for further refinement of the design. The rise of relatively cheap (€500–€1300) desktop 3D printers, such as RepRap, MakerBot Replicator 1, or Ultimaker (Kalish 2011) have allowed hobbyists and adopters of the do-it-yourself (DIY) culture to experiment, design, and produce things moving gradually from “prototyping” to “manufacturing.” However, lately 3D printers have been adopted, especially by aerospace and health care industries (Bullis 2011), to make functional products.

A strategic advantage of 3D printing is that it is capable of fabricating more complicated and intricate shapes than any other primary manufacturing technology (Bradshaw, Bowyer, and Haufe 2010) without the need of an inventory of new products, spare parts, and retooling (Campbell et al. 2011). Thus, it lowers the risk and the costs as well, as it reduces production constraints and barriers for entry into the business. 3D printing offers the geometrical freedom in engineering design and thus new chances exist for design in diverse industries such as aerospace, automotive, and bioengineering (Campbell et al. 2011). Moreover, this technological process reduces waste and harmful chemicals while offering the possibility to use recycled materials (Campbell et al. 2011) such as the common recyclable thermoplastic acrylonitrile, butadiene, styrene (ABS; Adams, Colborn, and Buckley 1993; Ashby and Johnson 2002; Biron 2007).

Further, 3D printing customizes and localizes production, lowering the need for an assembly line, reducing transportation and the carbon footprint. Finally, nanotechnology offers the potential to advance 3D printing materials through modification of their fundamental material properties, creating an increasing variety of novel materials: from metal and carbon nanoparticles (the latter can be used even for bone tissue engineering) to ceramics and semiconductors nanomaterials (Campbell et al. 2011). A recent project at the University of Glasgow shows that it is even possible to create chemical compounds, including new ones, using 3D printing technology with a low-cost open source printer such as the Fab@Home (Symes et al. 2004). In other words, this means that techniques from chemical engineering are made accessible to typical synthetic laboratories (Symes et al. 2004).

3D printing is predicted to continue to improve in capability, efficiency, and accuracy, and to use a wider range of materials (Atkinson 2006). The final frontier in 3D printing is "to introduce functional as well as structural materials, in order to print complete working systems," creating "one machine that can make anything" (Gershenfeld 2007). It is not, however, the only technology that can boost desktop manufacturing. Laser cutting and different kinds of milling machines or open hardware products, such as the microcontroller Arduino or the global village construction set of the Open Source Ecology project (discussed below), make it possible "to make (almost) anything" and develop solutions to local problems (Gershenfeld 2007).

The expansion of CBPP practices into physical production could arguably create networks of individual producers, cooperatives, nonprofit foundations, and for-profit companies which would work globally but produce locally. Of course, CBPP practices could not just be copied to and applied in the open design and open manufacturing realm without alteration, but must take into consideration the constraints of the material world (Troxler 2011). It seems that the desktop manufacturing technological capabilities will be related to a plethora of different models that may embrace various aspects of CBPP, "with users switching between different models as appropriate" (Troxler 2011, 94).

In contrast to the industrial paradigm whose competitive dynamics were about economies of scale, CBPP and desktop manufacturing, with the support of nanotechnology on the material level, could develop economies of scope. While the advantages of scale rest on cheap global transportation, which is facing problems because of the increasing oil prices and the environmental crisis (Rifkin 2011), economies of scope share infrastructure costs (intangible and tangible productive resources), taking advantage of the capabilities of the fabrication tools. Recognizing that "some of the least developed parts of the world need some of the most advanced technologies" (Gershenfeld 2007, 13-14), CBPP and desktop manufacturing may be the globally imagined tools that act locally (Perez 2002) in response to certain problems and needs, such as addressing the need for energy via small-scale energy production.

On the other hand, 3D printing processes have numerous drawbacks. To mention a few, they are limited for mass materials production purposes since, on average, they can create a 1.5 in. cube in about an hour (Campbell et al. 2011). Moreover, most 3D printing processes use proprietary polymers which are weaker than their traditionally manufactured counterparts, and the layer-by-layer fabrication process means that part strength is not uniform (Campbell et al. 2011). 3D printing processes repeatability needs improvement since parts made on different machines may have different properties (Campbell et al. 2011). Also, the expansion of desktop manufacturing technologies make weapons manufacturing easier since guns, bullets, bombs, and so on, could become cheaper, more accessible; not to mention that they could be more easily disguised (Campbell et al. 2011).

Overall, we assume for the current context that "the real issue is not technology per se, but the variety of possible technologies and paths of progress among which we must choose," (Feenberg 2002, v) trying not to be limited to a dichotomy between two polarized extremes (those who claim that technology is neutral and those who think that technology is malicious and threatening to humanity). For Feenberg (2002, 15), "technology is not a destiny but a scene of struggle ... a social battlefield", where individuals and social groups struggle to influence and change technological design, uses, and meanings (Feenberg 1999), and that is of course the case whether actually one of the two extremes just mentioned would be objectively correct or not. Our article attempts to show that a different form of social organization, as documented in the production processes of CBPP, is capable of emphasizing "other attributes of technology compatible with a wider distribution of cultural qualifications and powers" (Feenberg 2002, 35). In the conjunction of CBPP with desktop manufacturing, technology could be considered as subject to contestation, reconstruction, and democratic participation (Feenberg 1999) enabling people "to participate effectively in a widening range of public activities" (Feenberg 2002, 3).

The Helix_T Wind Turbine: A Case Study

Introduction to the Case

Glover (2006, 265), examining the first attempt to develop wind power from below in the 1970s, states that "renewable energy as a social solution has been doomed" to ask "what will be the transforming effect, if, in the not too distant future, such systems are easily ordered (perhaps from the Internet)?" (p. 266). The Helix_T project, with regard to Glover's concerns, tries to show that new means of production, such as the ICT and the emerging desktop manufacturing capabilities, could make possible not only the independent production of information but also the independent production of energy, even in such an infancy form.

The primary goal of the Helix_T wind turbine project—which was one of the authors' thesis at the Institute of Advanced Architecture of Cataluña (IAAC)—was to challenge the cost-effective ratio of small-scale wind turbines and to contribute to the debate about autonomous energy production at a low-cost, residential scale. It is important to highlight that the initiator of the Helix_T project is an architect/artist with an interest in elegant and operating design but with, at that time, almost no knowledge of mechanics. Thus, the second goal, set by necessity, was to see in which degree someone with a novel idea/plan, but without all the required skills for its effective and efficient implementation, can benefit from collaborating with dispersed, online open source/knowledge communities while using free/open source tools. In that way, it could be argued that not only the costs would be minimized but also the initial idea of the project could advance through social production processes.

While in many countries the sun shines for many hours per day, wind power on the other hand is more stochastic in terms of force as well as direction. Hence, the first question that was raised was whether wind turbines could be located in places where they can produce more power. Or to put it differently, what if we turned small-scale wind turbines into more of an urban grid, small power-producing devices? And for rural places, what if we develop modular small-scale wind turbines that could be combined to create a module that is larger and able to generate more power?

Studying the cases of artistic interventions in the city landscape such as the work of the Jason Burges Studio (2007, 2008) with the "wind to light" and "Aeolian tower" projects, the work of the circuit designer Yoshihiro Shimomura such as the "wind-it LEDs" (Meinhold 2008), the "Canopy" project by the United Visual Arts (2011), and the "flow project" (Vasquez 2010), it became evident that the wind turbine technology on a small scale could help an urban environment if it dealt with a smaller power-producing expectancy and at a targeted area of interest. These "areas of interest" are areas in the city landscape that normally have steady and powerful-enough winds fields throughout the year. Take, for example, narrow, long alleys, long hallways in buildings, metro entrances, metro tubes, big ventilation exhausts, and in general spaces that create air pathways due to shape or air pressure difference. By targeting these specific locations, one could make use of nonexploited wind and cover small energy needs at those specific locations.

Another question to deal with was whether, and how, it was possible to take advantage of the potential synergies of CBPP products and processes with desktop manufacturing. In other words, an additional goal was to use desktop manufacturing capabilities as well as CBPP products and processes to reduce the production costs of the wind turbine and at the same time to enhance its design and effectiveness, making it cheaper and friendlier to the environment while contributing a design blueprint to the Commons. Thus, to summarize, the aim of the Helix_T turbine project was to create an experimental wind turbine prototype that could be collaboratively developed globally and manufactured locally giving small amounts of clean energy when placed, for example, in urban spaces that could be called *wind power dumpsters*, or even when placed in rural places, especially concerning its sunflower-style combined mode as we discuss below.

Design and Fabrication

Our first attempt was to experiment with some basic wind turbine morphologies to see what kind of power could be achieved, and how, with amateur low-cost design. At that time, we had no knowledge of technical nature other than some basic mathematics on how the wind can be collected. Many wind turbine designs were found through extensive research in open source and DIY web platforms, such as the Instructables web platform where users can share what they make and tap into a community of creative experts. In that way, we came in contact with these online communities and several designers who had more technical knowledge. This allowed us simultaneously to learn by peers while learning by doing. In that way, quickly enough the design started to improve, so that it could be more efficient in terms of shape and analogies corresponding to the desired energy ratio.

In order to gain a better insight, at this point, it would be helpful to note that there are mainly two types of wind turbines, the horizontal axis design and the vertical axis design (Bowles, Rollins, and Hawks 1979; Coton, Galbraith, and Jiang 1996; Hemami 2012; Manwell, McGowan, and Rogers 2010). There are various advantages and disadvantages to each design (Coton, Galbraith, and Jiang 1996; Hemami 2012; Manwell, McGowan, and Rogers 2010), but these do not matter for the aims of the current article. It is important to mention, though, that since wind direction is a random element, horizontal axis wind turbines lose efficiency when not aligned with the wind direction. A key advantage of the vertical arrangement of the main rotor shaft is that the wind turbine does not need to be pointed into the wind to be effective. So we decided to begin with a simple Savonius design, which is a type of vertical axis wind turbine named after its inventor, the Finnish engineer S. J. Savonius (1884–1931; Modi and Fernando 1989; Sargolzaei and Kianifar 2009; Wagner and Mathur 2009).

The first tests were run using the exhaust pipe of a huge laser cutter machine. It was a 15-cm radius pipe that constantly blew air at the back of IAAC's facilities. It can be claimed that this process could take place in other areas that have the same kind of steady wind flow in different parts of a city. The first results produced around 5 W of potential power. The design was not evolved enough and the Savonius style did not seem to help capturing the constant flow of the wind. Thus, we decided to experiment with our prototype's design and partly change it to Darrieus, which is also a type of vertical axis wind turbine invented by the French aeronautical engineer G. J. M. Darrieus (1888–1979). Because of the setting and attributes of the wind source, we managed to have a steady flow of around 4 m/s (in Barcelona, the city where the tests were run, the annual wind speed ratio is around 3–4 m/s, according to gaisma.com [2012]). Running the calculations, it became obvious that with this design, it was possible to get around 10 W of power. Considering the power consumption of various everyday objects, this kind of power could charge, for example, 3 AA batteries or power 9,000 LEDs (3 mm diameter) or four smartphone chargers or a home Wi-Fi router.

Using a 3D printer in the process was of great importance to the Helix_T project, and it had significant implications for the design of the wind turbine, as it had to become quite modular (Figure 1). We started using the RepRap, which is a 3D printer that can print most of its components and is distributed under the Commons-oriented GNU General Public License (Jones et al. 2011). The RepRap, designed by Adrian Bowyer and his team, was an ideal choice since it is the first open source 3D printer that can be built by almost anyone at a cost of approximately €500 in hardware and parts (Jones et al. 2011). To put the matter bluntly, if one has access to mechanical hardware parts, such as screws and metallic rods, one could make a RepRap 3D printer with almost zero cost. The number of RepRaps has been growing around the world since the initiation of the project in 2005: over 4,500 had been reproduced in a period of only thirty months, according to estimates by Jones et al. (2011). We then had also the chance in the IAAC's laboratory to use a more professional, high-end, 3D printer by Hewlett-Packard as well as the open source Makerbot, whose source of inspiration was the RepRap project (Pettis 2011). It is possible to watch on YouTube (2010) the 3D printing of the first version of our wind turbine's structure by a Makerbot. At the time of this writing (May 2013), there are

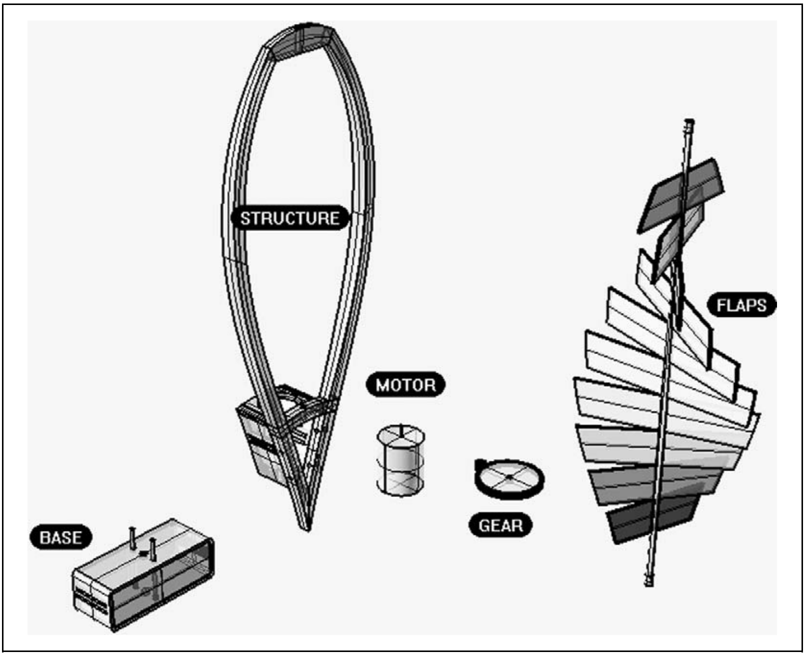


Figure 1. The modular parts of the Helix wind turbine. All are to be printed except for the motor.

many more low-cost models that can be used in the same, if not better, manner.

Working simultaneously with both open source and proprietary 3D printers, it became clear that the results were more or less the same on the scale that mattered to us (Figure 2). In addition, all these machines were using ABS plastic, which is very strong and relatively lightweight (Adams, Colborn, and Buckley 1993; Ashby and Johnson 2002; Biron 2007). Moreover, we used also polylactide acid, a biodegradable thermoplastic derived from natural lactic acid (Ashby and Johnson 2002), in order to have a less negative impact on the environment while its quality was almost the same with ABS concerning our wind turbine's function.

We then maximized the collection area of the Helix_T wind turbine and had to adjust the design to be printable by the maximum dimensions of a low-cost 3D printer. This provided a collection area large enough to theoretically harvest power up to 20 W, dependent on wind speed. The Helix_T wind turbine (Figure 3) is 34-cm long and its marginal cost of production is

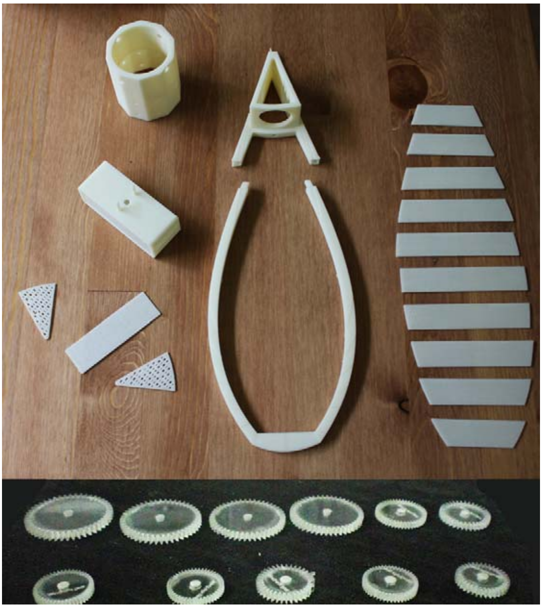


Figure 2. (a) The first three dimensional (3D) printed modular parts. (b) Different kinds of gears.

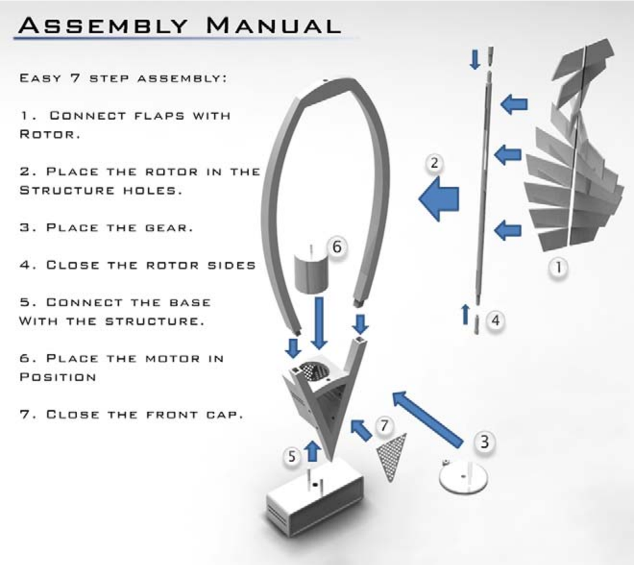
approximately €40–100 with an open source 3D printer, depending on print quality, the fee of the printers' owner, and power of motors which have to be separately bought.

Modularity is at the heart of the Helix_T project, as the design was adjusted to be able to work singularly or in plural, according to its setting. In a house, it could be mounted virtually anywhere with the help of belt straps and screws. The bottom part is a safeguard for the batteries and some electronic parts such as converters that form a power storage system for times when the power is not used, or when it exceeds its consumption.

The assembly of the wind turbine is quite easy (Figure 4) and with the help of small screws, it could be fitted into a 3D printable mass harvesting, modular device that was inspired by the sunflower (Figure 5). In this way, up to ten small-scale wind turbines could be used both in parallel connection and in a row. For instance, with the use of Arduino microcontrollers (popular open source single-board microcontrollers designed to make the

Figure 3. The Helix_T wind turbine V 1.00.

process of using electronics in multidisciplinary projects more accessible), it would be possible to create cooperation of modules that would arguably enhance the power production to its maximum. Such wind flowers could be planted in cities or in rural places, gathering power while giving an artistic vibe to squares, walkways, paths, or other points of interest at an urban or rural scale. In addition, the combination of artistic intervention into the city landscape with energy production, while the latter takes place in a subtle and arguably impressive way, was central to our project. For example, as several members of the open source communities commented, an even more elegant design could lead to wind gardens giving new aesthetic quality to spaces while producing power that could be used directly for the people or stored and given to different small power grids throughout the city. However, for the moment, the sunflower style (combined mode of several Helix_T wind turbines) has not been empirically realized, just theoretically, but this is a project on which we are currently working. Completing the circuit of the self-reproduction argument of this project, it is likely that such a sunflower could easily produce enough energy, with medium wind, for the popular open source 3D printer RepRap (theoretically speaking, under optimal conditions of steady and strong wind, even three Helix_T wind turbine modules could support the function of such a printer).



ASSEMBLY MANUAL

EASY 7 STEP ASSEMBLY:

1. CONNECT FLAPS WITH ROTOR.
2. PLACE THE ROTOR IN THE STRUCTURE HOLES.
3. PLACE THE GEAR.
4. CLOSE THE ROTOR SIDES
5. CONNECT THE BASE WITH THE STRUCTURE.
6. PLACE THE MOTOR IN POSITION
7. CLOSE THE FRONT CAP.

Figure 4. The assembly instructions document.

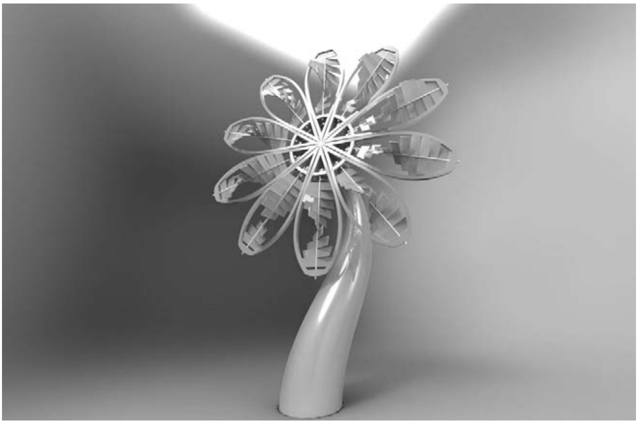


Figure 5. The sunflower-styled wind turbine consisted of ten small-scale wind turbines.

Results and Discussion of the Case

First, the Helix_T project shows that it can be possible to create low-cost, DIY wind turbine with 3D printed modules in an open source and cost-effective way to provide individuals with small amounts of clean energy. One obvious advantage of working with software (from ReplicatorG to Libre Office which are free alternatives to proprietary software) and hardware (e.g., RepRap and Arduino which cost less due to their open source licensing) produced by CBPP communities is that they both serve as valuable means of production lowering the final costs. Although there are many functional FOSS 3D design programs, such as the Art of Illusion, FreeCAD, or Blender, the final design of the Helix_T wind turbine was rendered with Rhino3D, a commercial program, as we were already very familiar with it and therefore, time wise, the learning curve for us was zero. However, it is possible to have the same results using any of the aforementioned FOSS 3D design programs, provided the users are knowledgeable in them. Blender (2012), which is used for creating 3D designs, animated films, interactive 3D applications, or video games, has a large user community of hobbyists and professionals eager to support newcomers as well as a helpful collection of electronic books (Wikibooks 2012). It could be argued that the development of low-cost desktop manufacturing may drive the development of correspondingly relevant FOSS design programs that will become more user-friendly, minimizing the learning curve while maximizing the quality of the results.

Further, we experienced and still experience a sense of pleasure and satisfaction when collaborating, communicating, and interacting with (new) people. The Commons-based communities and enthusiasts would support, advice, and contribute to solutions of problems we faced regarding software or hardware while practitioners and experts, who participated in open design, open manufacturing, and FOSS communities, would suggest ideas for further improvement. These interactions are central for CBPP and, as stated in the second section, are one of the main intrinsic motivations for participating in CBPP communities and projects.

Thus, being part of communities of enthusiasts helped us both to become knowledgeable of issues about which we previously had little knowledge and to achieve a greater overall performance. For example, learning to effectively work with a RepRap and the relevant FOSS would be considerably difficult were there not dozens of relevant online communities eager to help either providing their how-to answers and manuals or replying to our questions. Moreover, we had no previous background on the mechanics and electronics of wind turbines and, except for the relevant bibliography (Coton, Galbraith, and Jiang 1996; Hau 2005; Hemami 2012; Manwell, McGowan, and Rogers 2010), a great amount of knowledge was gained through Commons-based communities such as the Open Source Ecology (2012), which consists of a network of farmers, engineers, and enthusiasts whose goal is the manufacturing of an open source construction set; Thingiverse, which is an online platform dedicated in presenting home-made open source designs free for use and improvement; and, as it was mentioned above, the Instructables (2012).

Another example concerns the final adjustments of the electronics of the bottom part as well as in the final design of the modules, which were affected by suggestions made by Thingiverse users (discussed below in more detail). An improvement in the gear motor system was made through a combination of online and offline advice. The gear motor system, which led to the different gears that were tested on the wind turbine, was downloaded as a FOSS script. The know-how of assembling the gears with the motor as well as the different kind of motors that could be used was acquired through extensive collaboration with the community of Barcelona's hackerspace whose unconditional help was pivotal especially in the mechanical development of the project.

So, after the fulfillment of the Helix_T project's objectives, we decided to distribute all the designs of the project under a Creative Commons license (Attribution–Noncommercial–Share like). In this way, anyone would be able to reproduce the Helix_T turbine for nonprofit usage or work on the designs improving its efficiency, effectiveness, and modularity. We hope that individuals more knowledgeable in mechanics, electronics, and hardware would contribute to the Helix_T's enhancement, and so the designs were uploaded in Thingiverse (Fountouklis 2010) with the note that the project is always under development as an unfinished artifact in the style of CBPP (Bruns 2008). According to Thingiverse, the designs have been downloaded 1,152 times (May 2013), and we are aware at least of one case where the wind turbine has been 3D printed.

Moreover, crucial comments and proposals have been made (either publicly or in person) that have contributed to the advancement of different aspects of the project. For example, a Thingiverse user offered a piece of advice on the electronics of the wind turbine which substantially helps our research to find a way to stop the motor from discharging. Others (in person and on the Thingiverse platform) commented on the problems with the rotor, which has to become considerably thicker because it often cannot effectively hold the flaps. In addition, a problem with the structure of its lower clips has been pointed out (see Figure 2), and this needed to be strengthened so that it can now better withstand powerful winds. All these have led to changes in the designs of the Helix_T wind turbine that we are currently working on. While the 3D printing technology is rapidly evolving, offering better quality and manufacturing speed for lower prices and the CBPP movement seems to embrace larger parts of everyday life (van Abel et al. 2011), the design and efficiency of the Helix_T has the chance to reach its maximum potential and to be able to produce clean energy in the utmost cost-effective way.

Hence, at the time of this writing (May 2013), we are experimenting with Ultimaker, a new high-detail, low-cost open source 3D printer, taking into consideration the various shortcomings of the first version of Helix_T wind turbine's designs. To become more specific, first we have to deal with motor's discharge and enable energy saving; second, the design of the structure has to be enhanced as under strong winds it is possible to break; and third, the design and the endurance of the rotor need to be improved. Our primary aim is, based on the blueprint of the Helix_T wind turbine, to design and 3D print an advanced module with the final goal, as stated, to build and test an actual model of the sunflower-style wind turbine. Then, we will upload all the new blueprints in Thingiverse, and hopefully, the project will gain more popularity in terms of enthusiasts who will experiment with and further build on it.

Conclusion

This article set out to show, through the Helix_T wind turbine project, two things: first, on a theoretical level, that CBPP is not limited to ICT, but that in conjunction with the emerging technological capabilities of 3D printing, it can also produce really promising hardware, globally designed (with the direct or indirect support of Commons-based communities) and locally produced. Second, beyond its illustrative role as a case study, the Helix_T also contributes to the quest for novel solutions to the urgent need for (autonomous) renewable sources of energy, more as a development process and less as a ready-to-apply solution. And while the Helix_T does not offer huge amounts of energy and suffers from several shortcomings, we showed that it is possible to create a low-cost, DIY wind turbine with 3D printed modules in a cost-effective way to provide individuals with small amounts of clean energy. The illustration has also worked in theory by showing that it is possible to produce innovative hardware based on CBPP. The case shows that for someone with only very partial initial knowledge, it is feasible to start a similar project based on an interesting idea and to succeed in implementing it through the collaboration with Commons-oriented communities while using CBPP products and tools.

Given the trends and trajectories both of the ICT paradigm on one hand and the problems of the currently, still-prevailing industrial modes of production with all their collateral damage on the other, this may be considered both a positive result and a message. We trust that projects similar to Helix_T and projects that are more complex, such as the Open Source Ecology or the WikiSpeed car, will soon be investigated, documented, and analyzed by science, technology, and society scholars. More research could take place at the intersection of modes of social production and modern desktop manufacturing capabilities (from 3D printing via laser cutters to computer numerical control hobby-sized machines), since some, such as Anderson (2012), see there the emergence of an opportunity for an economy less driven by commercial interests and more by social ones. As a hyperproductive mode, CBPP forces the for-profit entities to adapt to its characteristics, "thereby further integrating it into the existing political economy, but not without the transformative effects of its market transcending aspects" (Bauwens 2009, 121).

This passionate mode of production (Moore and Karatzogianni 2009) may well be part of a new type of capitalism that has been developing since the beginning of the current ICT-based techno-economic paradigm, and that has many postcapitalistic aspects that may be capable, under certain circumstances, of rising to a dominant role and of building an alternative form of civilization in the distant future. For the present, CBPP and its conjunction with desktop manufacturing demonstrate the dimensions of technology that can be brought into play for the democratic reorganization of our industrial society as it exists, but from a different perspective than the tendentially atomistic and authoritarian culture of "modernity" (Feenberg 2002).

Declaration of Conflicting Interests

The Helix_T wind turbine project was Michail Fountouklis thesis at the Institute of Advanced Architecture of Cataluþa (Barcelona, Spain) part of the post-graduate program entitled "Open Thesis Fabrication" in 2010-2011. The authors would like to express their gratitude to Marta Male-Alemany, supervisor of the thesis project; Dimitris Spyrikos; Christos Giotitsas; two anonymous reviewers; and the Commons-oriented communities for their contribution to the project.

Funding

The realisation of this paper was supported by grants SF 014006 "Challenges to State Modernization in 21st Century Europe" and ETF 8571 "Web 2.0 and Governance: Institutional and Normative Changes and Challenges".

References

Ackermann, John. 2009. "Toward Open Source Hardware." *University of Dayton Law Review* 34 (2): 183–222.

Adams, M., R. Colborn, and D. Buckley. 1993. *Acrylonitrile-Butadiene-Styrene*. Shrewsbury, England: Rapra Technology.

American Society for Testing and Materials. 2010. "Standard Terminology for Additive Manufacturing Technologies, ASTM F2792-10." Accessed May 4. 2013 http://www.astm.org/Standards/F2792.htm.

Anderson, C. 2012. *Makers: The New Industrial Revolution*. London, England: Random House.

Ashby, Michael, and Kara Johnson. 2002. *Materials and Design: The Art and Science of Material Selection in Product Design*. Oxford, England: Butterworth-Heinemann.

Atkinson, Paul. 2006. "Do it Yourself: Democracy and Design." *Journal of Design History* 19 (1): 1–10. doi:10.1093/jdh/epk001.

Barefoot College. 2012. Accessed May 4. http://www.barefootcollege.org/default.asp.

Bauwens, Michel. 2005. "The Political Economy of Peer Production." *CTheory Journal*. Accessed May 4, 2012. http://www.ctheory.net/articles.aspx?id=499.

Bauwens, Michel. 2009. "Class and Capital in Peer Production." *Capital & Class* 33 (97): 121–41. doi:10.1177/030981680909700107.

Benkler, Yochai. 2006. *The Wealth of Networks: How Social Production Transforms Markets and Freedom*. New Haven, CT: Yale University Press.

Berry, David. 2008. "The Poverty of Networks." *Theory, Culture & Society* 25 (7-8): 364–72. doi:10.1177/0263276408097813.

Biron, Michel. 2007. *Thermoplastics and Thermoplastic Composites: Technical Information for Plastics Users*. Oxford, England: Elsevier Science.

Blender. 2012. Accessed May 4. http://www.blender.org/community/user-community/#c7834.

Bowles, D., J. Rollins, and R. Hawks. 1979. "Parametric Performance Analysis of a Darrieus Wind Turbine System." *Journal of Energy* 3 (3): 140–44.

Bradshaw, Simon, Adrian Bowyer, and Patrick Haufe. 2010. "The Intellectual Property Implications of Low-Cost 3D Printing." *ScriptEd* 7 (1): 5–31.

Bruns, Axel. 2008. *Blogs, Wikipedia, Second Life, and Beyond: From Production to Produsage*. New York: Peter Lang.

Bullis, Kevin. 2011. "GE and EADS to Print Parts for Airplanes." *Technology Review.* Accessed February 4. http://www.technologyreview.com/news/423950/ge-and-eads-to-print-parts-for-airplanes/.

Campbell, Thomas, Christopher Williams, Olga Ivanova, and Banning Garrett. 2011. *Could 3D Printing Change the World? Technologies, Potential, and Implications of Additive Manufacturing*. Washington, DC: Atlantic Council.

Castells, Manuel. 2000. *The Rise of the Network Society: Information Age*. 2nd ed. Oxford, England: Blackwell.

Castells, Manuel. 2003. *The Power of Identity: Information Age, Economy, Society, and Culture*. 2nd ed. Oxford, England: Blackwell.

Coton, F., R. Galbraith, and D. Jiang. 1996. "The Influence of Detailed Blade Design on the Aerodynamic Performance of Straight-Bladed Vertical Axis Wind Turbines." *Journal of Power and Energy* 210 (1996): 65–74.

Dafermos, George. 2012. "Authority in Peer Production: The Emergence of Governance in the FreeBSD Project." *Journal of Peer Production* 1 (1): 1–12. Accessed May 4. http://peerproduction.net/issues/issue-1/peer-reviewed-papers/.

Drechsler, Wolfgang, Rainer Kattel, and Erik Reinert. 2009. *Techno-economic Paradigms: Essays in Honour of Carlota Perez*. London, England: Anthem Press.

Feenberg, Andrew. 1999. *Questioning Technology*. New York: Routledge.

Feenberg, Andrew. 2002. *Transforming Technology: A Critical Theory Revisited*. New York: Oxford University Press.

Fountouklis, Michail. 2010. "Helix_T Windturbine." Accessed May 4. http://www.thingiverse.com/thing:5174.

Gaisma. 2012. Accessed May 4. http://www.gaisma.com/en/location/barcelona.html.

Gershenfeld, Neil. 2007. *FAB: The Coming Revolution on Your Desktop: From Personal Computers to Personal Fabrication*. Cambridge, MA: Basic Books.

Giseburt, Rob. 2012. "Is One of Our Open Source Heroes Going Closed Source?" *Make*. Accessed May 4. http://blog.makezine.com/2012/09/19/is-one-of-our-open-source-heroes-going-closed-source/.

Glover, Leigh. 2006. "From Love-ins to Logos: Charting the Demise of Renewable Energy as a Social Movement." In *Transforming Power: Energy as a Social Project*, edited by J. Byrne, N. Toly and L. Glover, 249–70. New Brunswick, NJ: Transaction Publishers.

Hau, Erich. 2005. *Wind Turbines: Fundamentals, Technologies, Application, Economics*. 2nd ed. Berlin, Germany: Springer.

Heilbroner, Robert. 1994. "Technological Determinism Revisited." In *Does Technology Drive History?: The Dilemma of Technological Determinism*, edited by L. Marx and M. R. Smit, 67–68. Cambridge, MA: MIT Press.

Hemami, Ahmad. 2012. *Wind Turbine Technology*. Clifton Park, NY: Delmar Cengage Learning.

Hertel, Guido, Sven Niedner, and Stefanie Herrmann. 2003. "Motivation of Software Developers in Open Source Projects: An Internet-Based Survey of Contributors to the Linux Kernel." *Research Policy* 32 (7): 1159–77.

Hess, David. 2005. "Technology- and Product-Oriented Movements: Approximating Social Movement Studies and Science and Technology Studies." *Science, Technology, & Human Values* 30 (4): 515–35. doi:10.1177/0162243905276499.

Instructables. 2012. "Turbines." Accessed May 2. http://www.instructables.com/id/Turbines.

Jason Burges Studio. 2007. "Wind to Light." Accessed May 4. http://www.jasonbruges.com/projects/uk-projects/wind-to-light.

Jason Burges Studio. 2008. "Aeolian Tower." Accessed May 4. http://www.jasonbruges.com/projects/uk-projects/aeolian-tower.

Jones, Rhys, Patrick Haufe, Ed Sells, Pejman Iravani, Vik Olliver, Chris Palmer, and Adrian Bowyer. 2011. "RepRap—The Replicating Rapid Prototyper." *Robotica* 29 (1): 177–91.

Kalish, Jon. 2011. "Ultimaker: There's a New 3D Printer in Town." *Make*. Accessed May 4, 2012. http://blog.makezine.com/2011/08/01/ultimaker-theres-a-new-3d-printer-in-town/.

Keen, Andrew. 2007. *The Cult of the Amateur*. New York: Doubleday.

Kostakis, Vasilis. 2009. "The Amateur Class, or, the Reserve Army of the Web." *Rethinking Marxism* 21 (3): 457–61. doi:10.1080/08935690902955179.

Kostakis, Vasilis. 2010. "Identifying and Understanding the Problems of Wikipedia's Peer Governance." *First Monday* 15. Accessed May 4. http://firstmonday.org/htbin/cgiwrap/bin/ojs/index.php/fm/article/view/2613/2479.

Kostakis, Vasilis. 2011a. "Commons-based Peer Production and The Neo-Weberian State: Synergies and Interdependencies." *Halduskultuur-Administrative Culture* 12 (2): 146–61. Accessed May 4. http://halduskultuur.eu/journal/index.php/HKAC/article/view/45.

Kostakis, Vasilis. 2011b. "The Political Economy of Information Production in the Social Web: Towards a "Partner State Approach." Doctoral dissertation, Tallinn University of Technology, Estonia.

Kostakis, Vasilis. 2012. "The Political Economy of Information Production in the Social Web: Chances for Reflection on Our Institutional Design." *Contemporary Social Science* 7 (3): 305–19.

Kostakis, Vasilis. 2013. "At the Turning Point of the Current Techno-Economic Paradigm: Commons-Based Peer Production, Desktop Manufacturing and the Role of Civil Society in the Perezian Framework." *TripleC* 11 (1): 173–90.

Kumar, Krishan. 1995. *From Post-Industrial to Post-Modern Society*. Oxford, England: Blackwell.

Lakhani, Karim, and Robert Wolf. 2005. "Why Hackers do What They Do: Understanding Motivation and Effort in Free/Open Source Software Projects." In *Perspectives on Free and Open Source Software*, edited by B. Fitzgerald, J. Feller, S. Hissam and K. Lakhan, 3–22. Cambridge, MA: MIT Press.

Lanier, Jaron. 2010. *You are not a Gadget: A Manifesto*. New York: Knopf.

Manwell, James, Jon McGowan, and Anthony Rogers. 2010. *Wind Energy Explained: Theory, Design and Application*. 2nd ed. New York: John Wiley.

Marx, Leo, and Merritt Roe Smit. 1994. *Does Technology Drive History?: The Dilemma of Technological Determinism*. Cambridge, MA: MIT Press.

Meinhold, Bridgette. 2008. “Wind-lit Solar LEDs: Powered by the Sun, moved by the Wind.” *Inhabitat*. Accessed May 4. http://inhabitat.com/wind-lit-solar-powered-by-the-sun-moved-by-the-wind/.

Mercier, Gaël, and Philippe Jean. 2006. “Nordic Folkecenter for Renewable Energy: ISCAN Report.” Accessed May 4. http://bit.ly/KPoJeX.

Modi, V., and M. Fernando. 1989. “On the Performance of the Savonius Wind Turbine.” *Journal of Solar Energy Engineering* 111 (1):71–81.

Moore, Phoebe, and Athina Karatzogianni. 2009. “Parallel Visions of Peer Production.” *Capital & Class* 97 (33):7–11. doi:10.1177/030981680909700101.

Mueller, Milton. 2010. *Networks and States: The Global Politics of Internet Governance*. Cambridge, MA: MIT Press.

Nea Guinea. 2012. Accessed May 4. http://neaguinea.org/.

Nordic Folkecenter for Renewable Energy. 2012. Accessed May 4. http://www.folkecenter.net/gb/rd/wind-energy/publications_downloads_wind/.

O’Mahony, Siobhán. 2003. “Guarding the Commons: How Community Managed Software Projects Protect their Work.” *Research Policy* 32 (7):1179–98.

Onawi. 2012. Accessed May 4. http://onawi.org/about-us/who-we-are-a-what-we-do.

O’Neil, Mathieu. 2009. *Cyberchiefs: Autonomy and Authority in Online Tribes*. London, England: Pluto Press.

Open Source Ecology. 2012. “Wind Turbine.” Accessed May 4. http://opensourceecology.org/wiki/Wind_Turbine.

Orsi, Cosma. 2009. “Knowledge-Based Society, Peer Production and the Common Good.” *Capital & Class* 33 (1):31–51. doi:10.1177/030981680909700103.

Patel, Mukund. 2005. *Wind and Solar Power Systems: Design, Analysis, and Operation*. 2nd ed. New York: CRC Press.

Perez, Carlota. 1983. “Structural Change and Assimilation of New Technologies in the Economic and Social Systems.” *Futures* 15 (4):357–75. doi:10.1016/0016-3287(83)90050-2.

Perez, Carlota. 2002. *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages*. Cheltenham, England: Edward Elgar Pub.

Perez, Carlota. 2007. “Respecialisation and the Deployment of the ICT Paradigm: An Essay on the Present Challenges of Globalisation.” In *The Future of the Information Society in Europe: Contributions to the Debate*, edited by C. Pascu, R. Compañó, A. Bianchi, J-C. Burgelman, S. Barrios, M. Ulbrich and I. Maghiros, 27–56. Technical Report EUR22353EN, IPTS, Joint Research Centre, Directorate General, European Commission.

Perez, Carlota. 2009. “Technological Revolutions and Techno-Economic Paradigms.” *Cambridge Journal of Economics* 34 (1):185–202. doi:10.1093/cje/bep028.

Pettis, Bre. 2011. "Made in my Backyard." In *Open Design Now*, edited by B. Van Abel, L. Evers, R. Klaassen and P. Troxler, 76–83. Amsterdam, the Netherlands: BIS Publishers.

Pettis, Bre. 2012. "Let's try That Again." Accessed April 2. http://www.makerbot.com/blog/2012/09/24/lets-try-that-again/.

RepRap wiki. 2012. Accessed May 4. http://reprap.org/wiki/Cost_Reduction.

Rifkin, Jeremy. 2011. *The Third Industrial Revolution: How Lateral Power is Transforming Energy, the Economy, and the World*. New York: Palgrave Macmillan.

Sargolzaei, Javad, and Ali Kianifar. 2009. "Modeling and Simulation of Wind Turbine Savonius Rotors using Artificial Neural Networks for Estimation of the Power Ratio and Torque." *Simulation Modelling Practice and Theory* 17 (7):1290–98.

Schiller, Dan. 1999. *Digital Capitalism: Networking the Global Market System*. Cambridge, MA: MIT Press.

Schiller, Herbert I. 1981. *Who Knows: Information in the Age of the Fortune 500*. Norwood, NJ: Ablex.

Schiller, Herbert I. 1984. *Information and the Crisis Economy*. Norwood, NJ: Ablex.

Schiller, Herbert I. 1996. *Information Inequality*. New York: Routledge.

Sombart, Werner. (1928) 1987. *Der moderne Kapitalismus. Historisch-systematische Darstellung des gesamteuropäischen Wirtschaftslebens von seinen Anfängen bis zur Gegenwart*. Reprint of the final edn., 3 vols. in 6. 1987, Munich, Germany: dtv.

Symes, Mark, Philip Kitson, Jun Yan, Craig Richmond, Geoffrey Cooper, Richard Bowman, Turlif Vilbrandt, and Leroy Cronin. 2004. "Integrated 3D-Printed Reactionware for Chemical Synthesis and Analysis." *Nature Chemistry* 4 (5): 349–54. doi:10.1038/nchem.1313.

Troxler, Peter. 2011. "Libraries of the Peer Production Era." In *Open Design Now*, edited by B. Van Abel, L. Evers, R. Klaassen and P. Troxler, 86–95. Amsterdam, the Netherlands: BIS Publishers.

Tuomi, Ikka. 2002. "The Lives and Death of Moore's Law." *First Monday* 11. Accessed February 4. http://firstmonday.org/htbin/cgiwrap/bin/ojs/index.php/fm/article/view/1000/921.

United Visual Arts. 2011. "Canopy." *BeyondRisør*. Accessed March 25. http://www.beyondrisor.no/blog/?p=616.

van Abel, Lucas Evers Bas, Roel Klaassen, and Peter Troxler. 2011. *Open Design Now*. Amsterdam, Netherlands: BIS Publishers.

Vasquez, Alberto. 2010. "Flow-Public Lighting for the Third World." Accessed May 4. http://www.behance.net/gallery/Flow-public-lighting-for-the-Third-World/446201.

von Hippel, Eric, and Georg von Krogh. 2003. "Open Source Software and the 'Private-Collective' Innovation Model: Issues for Organization Science." *Organization Science* 14 (2):209–23.

Wagner, Hermann-Josef, and Jyotirmay Mathur. 2009. *Introduction to Wind Energy Systems: Basics, Technology and Operation*. Heidelberg, Germany: Springer.

Webster, Frank. 2002a. *Theories of the Information Society*. New York: Routledge.

Webster, Frank. 2002b. "The Information Society Revisited." In *The Handbook of New Media*, edited by L. A. Lievrouwand and S. Livingstone, 22–33. London, England: Sage.

Wikibooks. 2012. "Blender 3D." Accessed May 4. http://en.wikibooks.org/wiki/Blender.

Youtube. 2010. "Helix_T 3D Printed Windturbine." Accessed May 4. www.youtube.com/watch?v=z_qZLEYUavA.

Author Biographies

Vasilis Kostakis is currently a research fellow at Tallinn University of Technology and a collaborator of P2P Foundation. He is the founder of P2P Lab.

Michalis Fountouklis is an architect and 3D designer interested in experimenting with 3D printing s artistic interventions to practical applications on architecture. He is a collaborator of P2P Lab.

Wolfgang Drechsler is professor and chair of governance at Tallinn University of Technology.