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How to Reap the Benefits of the "Digital Revolution"? Modularity and the Commons

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Abstract

A significant potential of the digital revolution has not been fully realized. A contextual shift has to take place to build institutions that would harness the power of a fundamental aspect of digital technologies: modularity. I show why modularity lies at the heart of digital technologies and describe its strengths and drawbacks. Further, I discuss an emerging mode of production premised on modularity, which may point towards a more sustainable and inclusive digital transformation yet to come.

Keywords: innovation, commons, technological change, industrial organization, manufacturing, sharing economy

1. Introduction

Capitalism is a creative-destruction process that revolutionizes the economic structure from within, destroying the old structure while creating a new one (Schumpeter 1950). Studying the economic history since the first industrial revolution, Perez (2002) suggests that capitalism reinvents itself every 40-70 years. In each reinvention, there is a pattern of a new common sense coupled with a new set of complementary and pervasive technologies (Perez 2002). This new common sense permeates the way people produce, the way they consume, and the way their institutions are organized (Perez 2002).

Perez (2002) argues that capitalism has experienced five technological revolutions[1]:

1. the first industrial revolution based on machines, factories, and canals (initiated in 1771; birthplace: Britain);
2. the age of steam, coal, iron and railways (1829; birthplace: Britain);
3. the age of steel and heavy engineering (1875; birthplace: Britain, USA, and Germany);
4. the age of the automobile, oil, petrochemicals and mass production (1908; birthplace: USA);
5. and the age of information and communication technology (ICT) (1971; birthplace: USA).

Each technological revolution evolves "from small beginnings in restricted sectors and geographic regions" and ends up "encompassing the bulk of activities in the core country or

1 I use the notion of "technological revolution" in the way Carlota Perez and other neo-Schumpeterians use it; meaning "a set of interrelated radical breakthroughs, forming a major constellation of interdependent technologies; a cluster of clusters or a system of systems" (Perez 2010, 189).

countries [birthplaces] and diffusing out towards further and further peripheries, depending on the capacity of the transport and communications infrastructures” (Perez 2002, 15). Each technological revolution leads “to structural changes in production, distribution, communication and consumption as well as to profound and qualitative changes in society” (Perez 2002, 15).

At the beginning of a technological revolution, new technologies erupt in an economy that includes old, maturing and declining industries. The rapid development of such new technologies requires a great deal of finance. This is when a frenzy of investment creates financial bubbles and turbulent times arrive – that is, collapse, recession, and instability (Perez 2002, 2009, 2010). Reflecting on Hegelian dialectics (Hegel 2018), the first period, i.e. the installation period of the revolution, is too “abstract” and thus needs a “negative”, i.e. a process of contextual shift or what Perez (2002) calls a “turning point”. The essential potentialities of the new technologies need to be identified, the fallacies and the unsustainability of the dominant practices need to be recognized, and institutional innovations to occur. The best parts of the installation period need to be rescued and the “negative” to be absorbed.

This contextual shift enables economies to take advantage of the new technologies across all sectors and spread the benefits of the new wealth-creating potential across society. Echoing Hegel (2018), after the “negative” comes the “concrete”: what Perez considers the deployment period that includes synergies among many societal stakeholders. In this period, the governments, entrepreneurs, and the civil society have a clearer understanding of the policies and the changes that need to take place.

So, according to Perez (2009, 2010), since the introduction of the microprocessor (California, November, 1971), and after a nearly four-decade-long paroxystic culmination of market experimentation, we are in the aftermath of two major bubbles (the NASDAQ collapse in 2000 and the financial crisis of 2007-2008) and amid a systemic crisis. The world is at the turning point and needs to reap the full benefits of the digital revolution, create the new fabric of the economy and overcome the tensions that led to two major bubbles (Perez 2002, 2009, 2010) (Figure 1).

This article argues that independently of whether one aims to build a green growth, degrowth, social democratic, communist or any future, one should be aware of a fundamental aspect of the digital technologies: modularity. Modularity is a property that describes the degree that standardized parts or independent units are used to construct a more complex system (Oxford Dictionaries 2019). A system can be an artifact, a structure or even a process. So, such a system is broken into modules of varying degrees of interdependence and independence based on predetermined abstractions and a set of rules or standards.

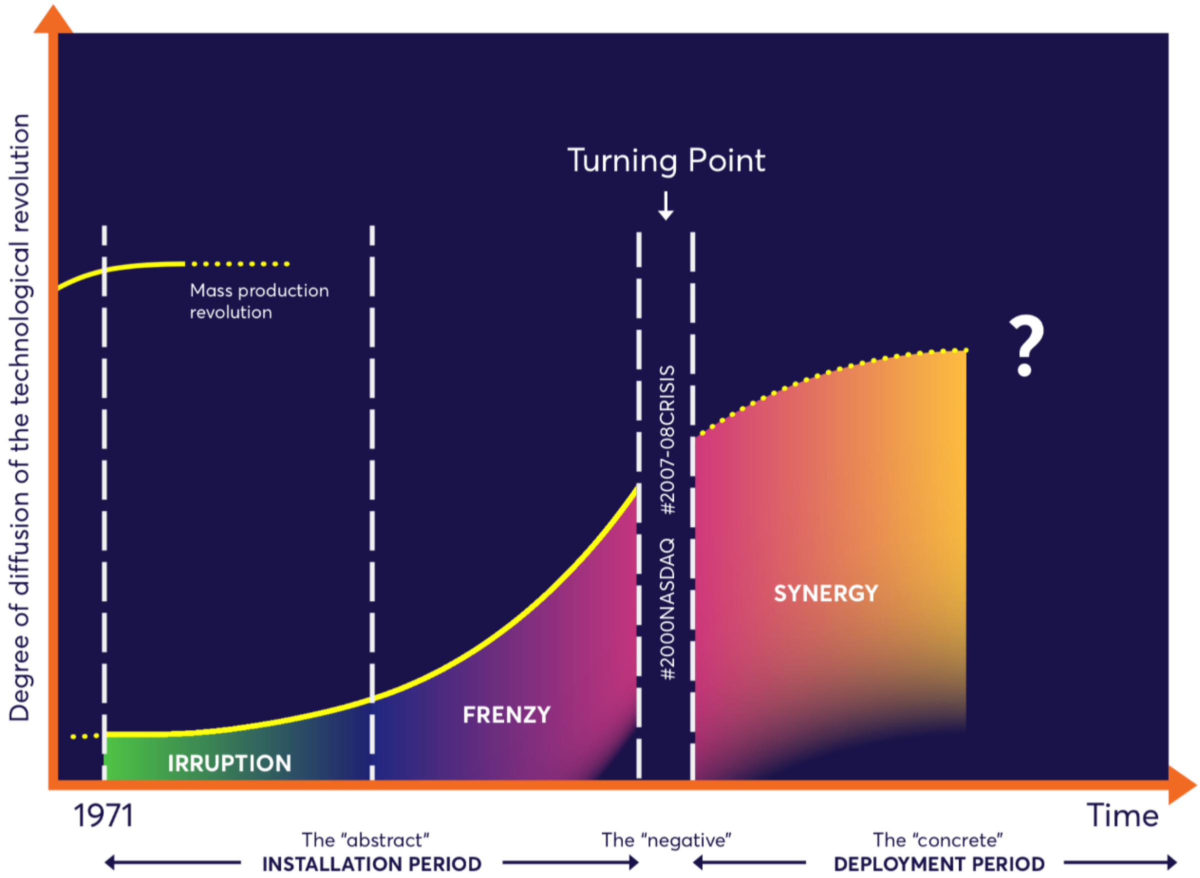

Figure 1: The techno-economic paradigm brought to the fore by the digital revolution is at a turning point, and a contextual shift is necessary.

The digital revolution has engendered radical changes in the production processes in almost all industries (Perez 2010; Kattel et al. 2009). Significantly enhanced technological and organizational capabilities have introduced modularity into production processes and networks (Berger 2006; Kattel et al. 2009). The industry that epitomizes the ICT-driven paradigm is the computer industry. It is thus within the computer industry that such new organizational forms and production processes more effectively taking advantage of the digital technologies have emerged. As discussed below, modularity empowers the leading organizations of the digital revolution.

To spread the benefits of the digital revolution across society, much modularity-oriented institutional innovation is necessary. However, the way that modularity-infused policies and practices are implemented is not politically neutral. This paper argues for commons-based modularity that may reap the benefits of modularity towards a more inclusive and environmentally sustainable paradigm.

Section 2 focuses on the essence of being digital and shows why modularity lies at the heart of digitalness. Section 3 discusses the strengths of modularity, drawing insights from the organizational and industrial ecology literature. Section 4 brings examples that demonstrate an alternative technology model to the profit-maximizing one, to argue that the former can make the best out of digital technologies if the goal is to build institutions that will be inclusive and environmentally sustainable. The last section concludes by summarizing the main messages of this article.

2. Demystifying digital technology

What is digital? Etymologically the word is derived from the Latin "digitus", which stands for finger or toe, and arose from the practice of counting on the fingers (Wiktionary 2019; Oxford Dictionaries 2019). An abstract practice in which each finger is a module. Counting on the fingers is a modular system composed of modules "designed independently but still function as an integrated whole" (Baldwin and Clark 2003, 151). The fingers (modules) are combined, and they compose a set of values. For example, three fingers stand for three and two palms stand for ten. And by using more levels of abstraction, it is even possible to count on the fingers to 99 (see the Chisanbop method from Korea).

Nowadays, digital "describes electronic technology that generates, stores, and processes data in terms of two states: positive and non-positive" (Jansen and James 2002, 130). It can thus be considered a property of representing values as distinct digits rather than a continuous spectrum. The positive and the non-positive values are two discrete digits: 1 and 0. The abstract decision to represent values as 1 and 0 enables modularity. 1 and 0 are modules that contain information: 1 stands for high voltage and 0 for low voltage. When combined they create more complex meaningful structures, using prior infrastructures for organizing and interpreting threads of these two digits. To be digital is therefore to be modular.

So, how digital (or modular) are the technologies that are considered as such? For example, let us compare the digital clock, which displays the time in numbers, to the analogue clock, which indicates time by the positions of rotating hands. In this case, digital refers only to the display. The drive mechanism can either be mechanical or electronic, modular or integrated. Therefore, the digital clock may be partly digital technology. Further, 3D printing is considered a digital fabrication process (Gershenfeld 2012; Kostakis and Papachristou 2014) because, first, some of the drive mechanisms are electronic and, second, a digital 3D model guides the 3D printer. The former contains discrete binary digits translated by the 3D printer's software into a digital object. In this way, the 3D printer builds a physical object. But is 3D printing a digital technology? And if yes, how digital is it?

Gershenfeld (2012; Gershenfeld et al. 2017) compares the assembling of Lego bricks with 3D printing. A child assembles the Lego bricks more accurately than its motor skills would allow. The Lego bricks (modules) are designed to snap together in alignment; they contain information embedded in their design. The Lego bricks are also available in different colors and materials and can be disassembled and reused. On the other hand, 3D printing accumulates errors, has a limited ability to use dissimilar materials, and the 3D printed artifacts cannot be disassembled (Gershenfeld 2012; Gershenfeld et al. 2017). Therefore, 3D printing involves integrated manufacturing that draws upon digital files. Lego demonstrates how processes and structures can be simplified into discrete and interoperable modules.

Hence, when one uses the term "digital", one should be aware of the (co-)existence of various degrees and understandings of digitalness. Being digital is context-specific. So is technology. Technology may not only refer to artifacts, such as the 3D printer, the clock or the Lego bricks. Technology also entails processes, such as designing the technological artifact, and the relevant knowledge, such as the know-how regarding the manufacturing, use, and maintenance of a technological artifact (MacKenzie and Wajcman 1999; Giotitsas 2019). Not only are the technological artifacts that define the current technological revolution less digital than many may think, but their production, use, and maintenance may be less digital, too.

3. The power of modularity

In nature, modularity has been ubiquitous for billions of years – from the construction of the DNA and the RNA by joining together nucleobase modules (adenine, cytosine, guanine, uracil, thymine) to the hexagonal cells in a honeycomb. Modularity has also been ubiquitous in the history of human design and construction: from the neolithic shelters and the pyramids of Egypt to the aqueducts of Rome and the Chinese Great Wall (Gentile 2013).

However, it is in the ICT-driven technological revolution that humanity reached such a level of innovation by building complex products from smaller subsystems, designed independently yet functioning together as a whole (Baldwin and Clark 2000, 2003). Baldwin and Clark (2000) use the computer industry as a case to address the power of modularity because it has the highest degree of modularity compared to other sectors. The degree of modularity describes the degree of coupling between different modules (Persson and Åhlström 2006). Thus, 100% modularity in design means that one function is allocated to one single module while 0% means that all functions are allocated to all different modules (Erens and Verhulst 1997; Ulrich 1995).

The computer includes a perplexing cluster of rapidly changing elements (hardware and software) that function in concert. Modularity enables the handling of this increasingly sophisticated technology. Once a product is broken up into modules, designers, producers, and users gain flexibility while different organizations can work on separate modules knowing that their autonomous efforts will result in a functional artifact (Baldwin and Clark 2000). Modularity, backed-up by ICT, is also increasingly used in other industries, such as in the automotive industry by Toyota and Volkswagen (Pandremenos et al. 2008; Baldwin and Clark 2003), in aircraft manufacturing by Airbus and Boeing (Buergin et al. 2018; Tang et al. 2009), in housing (da Rocha et al. 2015; Priavolou 2018), or in home appliances by Haier (Hamel and Zanini 2018).

Modularity enables different groups to work independently on modules, push deeper into their processes and thus boost the rate of innovation (Baldwin and Clark 2003). The module participants are free to engage in parallel experiments with a wide range of approaches, under the condition that they follow the design rules that allow the modules to fit together (Baldwin and Clark 2003). Therefore, a modular system may offer flexibility and variety in its use and improvement, provided everybody agrees to the overarching rules (Ulrich 2003). This makes complexity manageable by enabling autonomous experimentation in unforeseen ways (Baldwin and Clark 2003). In addition, commonly mentioned benefits of modularity include cutting down the communication or transaction costs due to distributed problem-solving, enhanced reusability, easier and longer maintenance of the artifact, and advanced customization (Jose and Tollenaere 2005; van Liere et al. 2004; Pekkarinen and Ulkuniemi 2008; Gentile 2013; Garud et al. 2003).

Nevertheless, if technology entails the artifact, the production processes, and the knowledge about the use and the maintenance of the artifact, how can modularity be conceived? Building on Bask et al. (2010) and Baldwin and Clark (2003), four types of modularity can be distinguished:

- Modularity in artifact design: It refers to the decomposability of an object into smaller subsystems that may be designed independently but still function together as a whole. For example, see the desktop personal computer that includes the motherboard, the processor memory, the case/chassis, the power supply, the floppy disk etc.
- Modularity in production processes: It refers to the way that the artifact is produced. Production includes the whole value chain of an artifact, from its design to its manufacturing and distribution. Modularity in production is often a result of increased modularity in design (Brusoni and Prencipe 2001). Modularity in design is connected to the outsourcing of tasks; however, it is not clear which begets the other (Campagnolo and Camuffo 2010). For example, see how the parts of an iPhone are produced by several suppliers from Japan, China and Korea to Italy and the USA.
- Modularity in use: It refers to the possibility that the users may have to mix and match modules so that the artifact suits their needs as well as their ability to maintain them. For example, see the modular shelving systems of IKEA that allow the users to build their bookcases by combining various shelves, using glass or wooden covers, adding lighting or substituting a broken shelf with a new one.
- Modularity in services: It refers to a "system of components that offers a well-defined functionality via a precisely described interface and with which a modular service is composed, tailored, customized, and personalized" (Tuunanen et al. 2012, 101). For example, see the Assisted Living Facilities of the Dutch mental healthcare institutions that customizes the residential care people receive to their needs for self-development (Soffers et al. 2014). The healthcare service is decomposed into parts that can be mixed and matched in various ways and thus form a functional whole (Soffers et al. 2014). The modularity in services is an emerging, more complex and context-specific manifestation of modularity (Bask et al. 2010) and may be approached on a case-by-case basis (for a list of diverse case studies of modularity in service see Brax et al. 2017).

So, modularity is not limited to design, but it can also or instead encompass processes of the value chain of an artifact. An organization, an institution or an individual can employ or combine any of these types of modularity. The leading organizations of the digital revolution have arguably gained their competitive advantage, among other reasons, because of the effective integration of modularity into their business models. Modularity allows for-profit firms such as Apple, Samsung, and Amazon to outsource the manufacturing of their products and, in addition to the already stated benefits of modularity, to profit from cheap labor. They may hide the modularity from end-users, and sell the product as a new whole. This enables them to have control over how the modules are integrated into the final product making it hard to swap modules independently.

Further, IBM, Google, and Facebook benefit from crowdsourcing part of their value chain to freelancing or voluntary labor (e.g. the Android ecosystem, the free and open-source software, or the community-based content creation) (Kostakis and Bauwens 2014; Bauwens et al. 2019). Moreover, Haier, the world's largest appliance maker, has adopted a modular form of organization orchestrating a network of hundreds of interconnected micro-enterprises (Hamel and Zanini 2018). Airbnb benefits from modularity, too (Han et al. 2018), offering its customers customized and tailored services (apartment renting, tourist guiding, etc.).

Modularity has also enabled commons-based organizations to scale-up and even outperform their for-profit competitors (e.g. Wikipedia vs. Britannica and Microsoft Encarta, the Apache HTTP Server vs. the Microsoft ISS). Building on Benkler (2006), von Hippel (2016), and Baldwin and von Hippel (2011), I argue that the commons-based initiatives may frequently demonstrate the most effective ways to reap the benefits of the digital revolution. Their commons orientation allows for cooperation beyond the constraints of time and place. A modular understanding of digitalness enables us to explore the deployment of the digital revolution under different political economies. The next section discusses the transformative power of the commons and how they may overcome some of the shortcomings of modularity.

4. The emergence of commons-based peer production: opportunities and challenges

The increasing availability of ICT has made information sharing and grassroots cooperation possible on such a scale that a new mode of production has been emerging: commons-based peer production (Benkler 2006). Commons-based peer production (CBBP) involves Internet-enabled structures that allow people to communicate, self-organize and co-create a commons, i.e. a shared resource, co-governed by its user or productive community according to the rules and norms of that community (Ostrom 1990; Bollier 2014). In CBPP, participants govern the work through participatory practices and create public value that can be used in new iterations (Bauwens et al. 2019).

There is a growing ecosystem of CBPP initiatives. For example, see the free encyclopedia Wikipedia, which has displaced the corporate-organized Encyclopaedia Britannica and the Microsoft Encarta (Silverman 2012; Cohen 2009) or the free and open-source software projects, such as the GNU/Linux that drives the top 500 supercomputers (Top500 2018) or the Apache HTTP Server that is the leading software in the web-server market (Netcraft 2018). While the first wave of CBPP included knowledge and software projects, the second wave seems to be moving towards design, which, when linked to the production of open hardware, can impact manufacturing (Rifkin 2014). For example, see the production of a wide range of artifacts: from low-cost 3D printers that have shaped a multi-billion-dollar market (Reprap 2018; SmartTech 2016; McCue 2018), to agricultural machines for small-scale farming (Giotitsas 2019), to low-cost prosthetic arms, and to off-grid wind and hydro-electric power generators (Kostakis et al. 2018).

One organizational and production configuration for CBPP has been described as “design global, manufacture local” (Kostakis et al. 2015; 2016; 2018). It reverses the industrial logic of restrictive intellectual properties and global supply chains feeding into economies of scale. Instead, intellectual property is, as a commons, accessible to everyone, with knowledge production taking place openly on a global scale. Manufacturing takes place locally by communities or enterprises, often through shared infrastructures and with regional biophysical conditions-needs under consideration. It embraces the idea of circular economies rejecting the decontextualization of inputs-outputs and related externalities. Therefore, the production seems to be oriented towards sustainability and well-being rather than economic growth. Hence, in addition to the large-scale CBPP initiatives such as Wikipedia and GNU/Linux, small-scale initiatives can also be influential on a larger scale as nodes in a commons-based global network of local networks. Grassroots initiatives, which are organized around shareable informational modules, can have both a local and a global orientation.

Modularity is a core characteristic of CBPP (Benkler 2006). For example, on Wikipedia, the content is broken down into smaller components: entries, sections, or paragraphs. People can contribute from one word to thousands of words (or figures). So, the modules allow for any size of the contribution to match different levels of contributors' motivation and time availability – a property called "granularity" (Benkler 2006). Further, it is easy to put the various contributions into the final product. Similar design properties characterize the free and open-source software and the open hardware realm. Modularity enables sharing and human creativity through asynchronous and synchronous collaboration, going beyond the limitations of time and space. To quote Manzini (2013), "the small and the local, when they are open and connected, can, therefore, become a design guideline for creating resilient systems and sustainable qualities, and a positive feedback loop between these systems". Hence, in addition to "scaling-up", CBPP initiatives are "scaling-wide".

To illustrate, from a modularity perspective, the relations forged by the emergence and the interaction of diverse CBPP ecosystems, I use the case of Farm Hack. The reason is that Farm Hack is about agriculture and is thus related to all three economic sectors (primary: production of raw materials; secondary: manufacturing; tertiary: services). Moreover, it is directly and indirectly connected with a wide range of different CBPP initiatives. Hence, it is a paradigmatic case (Mills et al. 2010). The information regarding this initiative is drawn from Giotitsas (2019; personal communication), who did an in-depth study of Farm Hack, as well as from the openly available material on its website (Farm Hack 2019).

Farm Hack is a community of farmers which promotes tools and machinery designed and developed following the open-source principles. It emerged as a collaborative effort of farmer activists in the USA to brainstorm and produce ideas for various tool-related problems on a farm. Since 2011, Farm Hack has grown to include a large and decentralized community comprised mostly of farmers. The Farm Hack community built a digital platform based on free and open-source software. The platform functions as a communication, coordination, dissemination, and technology-development tool. It is primarily a database of tools that have been built, modified and shared by the community. The tools are available under a Creative Commons license for everyone to freely use and modify, under the condition that they will release the designs under the same license.

Farm Hack also brings together farmers, designers, engineers, academics and activists in events to engage in dialogue; skill development; tool design, building and demonstration. Farmers from all over the world have contributed to the Farm Hack platform, which, at the time of this writing, contains more than 500 tools. Several of these tools involve the use of other CBPP projects, such as a Fido Cellular[2] (includes an Arduino microcontroller) or a Seeder

2 https://farmhack.org/tools/fido-temperature-alarm-sends-text-messages

Roller[3] (printable by a RepRap 3D printer). The content (along with the platform itself) is open to improvement or modification from whoever joins the platform.

The Farm Hack community has a local orientation and impact while it shares its intangible resources as a global digital commons. Thus, we observe the emergence of synergetic collaborative networks such as those described by Manzini above (2013; and for a detailed discussion see his 2015 book). For example, Farm Hack is connected with another similar community from France, L'Atelier Paysan. L'Atelier Paysan is a cooperative that develops commons-based farmer-driven technologies and practices. Together, Farm Hack and L'Atelier Paysan improve the same digital commons. Further, more communities from other parts of the world have been joining this network, which is not officially established but mostly works in an asynchronous collaborative manner. Each initiative has its unique characteristics, as each is born in and is influenced by its context-specific environments, although all may be oriented towards similar goals (for an in-depth discussion of Farm Hack's and L'Atelier Paysan's culture and characteristics, see Giotitsas 2019).

So, the Farm Hack platform is based on and consists of the following modules produced by other CBPP initiatives (the list is indicative):

- Software produced by CBPP communities: Drupal (which integrates a Wiki), Wordpress, Apache Web Server.
- A license produced as a commons by the Creative Commons community.
- Designs, bill of materials, manuals and software of tools for small-scale agriculture, from sensors to cultivating machines, produced as a commons by the Farm Hack community and other CBPP communities, such as L'Atelier Paysan.
- The Web and the Internet infrastructure that, in no small extent, is a commons.

Following the four types of modularity, Farm Hack may exhibit:

- Modularity in design: Some of the tools follow a modular design, others follow an integrated design strategy. This may depend on which strategy is the most appropriate for the producer/user to achieve their goals.
- Modularity in production: The design and manufacturing capacities for building the tools are distributed (commonified) and thus modularized. This distribution differs from a mere distribution of tasks across the supply chain (e.g. cases of globalized assembly of parts), which alone does not necessarily lead to a high degree of modularization. The critical factor is frugal and transparent design, which provides agency to various levels and qualities of technical capacities and expertise to participate in the production.
- Modularity in use: The user is free to improve the design and adjust the manufacturing to their needs and resources, also considering the local biophysical conditions and materials. The technological artifact may serve more than one purpose at the same time with the necessary adjustments. Also, its maintenance is arguably easier, as all knowledge is open, and the user, maybe with the help of an expert, can freely study its inner workings and thus maintain the tool without being locked in.
- Modularity in service: The Farm Hack platform provides support and community-building services, which facilitate the building-up of social relations (social commons). It offers

3 https://farmhack.org/tools/seeder-roller-generator-jang-seeders

varying degrees of utility, e.g. people can participate in workshops to learn how to build tools; they can organize them and build their tools; but they can also buy pre-assembled parts or whole tools ready to use. They can thus benefit from the Farm Hack value chain at will. The platform also includes a shop, which promotes entrepreneurial activity in line with the Farm Hack spirit and ideology.

One key difference of CBPP initiatives, such as Farm Hack, from traditional for-profit ones is that the former primarily produce use-value for their communities (von Hippel 2016; Benkler 2006; Bauwens et al. 2019). Their aim is not to maximize profits, but to maximize the sharing and impact of the community-built value. The commons orientation has the potential to address some of the shortcomings of modularity as identified by studies of for-profit implementations.

First, CBPP products are not intentionally designed to become obsolete (Kostakis et al. 2018); of course, one may want to create a product to last as long as possible but eventually fail to do so. The motivation to design for sustainability may address the negative environmental impact of certain modular products due to the planned obsolescence coming from the continual introduction and replacement of modules. To increase profits, some companies may adopt such practices (Agrawal and Ülkü 2013). This depends on the incentives of the producer and the over-arching political economy.

Further, another challenge is that a modular product is easy to be copied or imitated by competitors. Hence, some companies may choose to follow an integrated product architecture to keep the relevant knowledge inside the company and avoid imitation (Persson and Åhlström 2006; Seliger and Zettl 2008; Lau 2011). In the for-profit-maximization setting, critical design knowledge and expertise may also be transferred to suppliers (Shamsuzzoha et al. 2008), with whom the outsourcing company may stop cooperating. In CBPP, all knowledge is commonified, thus, such dangers do not exist. Knowledge is not a rival but an anti-rival resource because sharing enhances its value (Bauwens et al. 2019; Benkler 2006; Baldwin and von Hippel 2011). Shared knowledge may enable designers, who are also the users of the product, to have a thorough understanding of the inner working principles of the overall product or process. So, learning may be faster and product development less expensive as a result of permissionless collaborative efforts.

Moreover, Sonego et al. (2018) highlight the need for user-driven design so that the users become more engaged in the maintenance of the product and the producers understand when and how to implement modularity. In CBPP, users are often actively consulted in every step of the technological development process or are the ones developing the artifacts (von Hippel 2016; Giotitsas 2019).

Besides, modularity may hinder optimization (Gershenson et al. 2003; Lau 2011; Pandremenos et al. 2012). By containing redundant physical structure, modular designs may not exploit as much function-sharing as is possible (Ulrich and Seering 1990; Ulrich 1995). For instance, in an automobile, if the alternator and the engine are designed as separate modules, more physical structures (e.g. support bracket, alternator housing) associated with the alternator are needed. In an integrated design, the former would be enclosed in the engine block (Ulrich 1995). In CBPP, shared knowledge and designs create a broader spectrum of options for module functionality and association, while common “protocols” guide their fixation in the integrated structure. Also, the possibility for localized manufacturing with the freedom to adapt and adjust the knowledge into the local setting (desirable product architecture, culture, environment, needs, materials) may allow for further functional and cultural optimization and customization. Hence, the integrated design optimizes “at the center”, i.e. focusing on the pre-engineered function of the artifact; CBPP delegates optimization processes “at the edges”, following the user perspective rather than engineering requirements. The abovementioned “design global, manufacture local” configuration bears such a dynamic (Kostakis et al. 2015; 2016; 2018; Giotitsas 2019).

CBPP is an emerging phenomenon, and thus more research is needed to provide robust evidence and a deeper understanding of its dynamics and limitations. Kreis, Finn and Turner (2011) discuss the limits of CBPP and highlight unaddressed issues of the phenomenon. For example, under which conditions may CBPP be a subtly coercive expansion of the workplace into everyday life? Does CBPP develop institutional mechanisms that secure bureaucratic values such as inclusion and accountability? What is the power or influence of the emerging charisma-driven clans?

Moreover, so far, CBPP does not directly address the criticisms and problems of ICT regarding resource extraction, exploitative labor, energy use or material flows (Kostakis et al. 2018). Even the argument that CBPP does not include planned obsolescence rests on poor empirical data (Kostakis et al. 2018). In addition, CBPP currently cannot, and probably will not, substitute all production processes nor work better than centralized infrastructures in specific contexts (Kostakis et al. 2015).

Further, some of the shortcomings of modularity, such as path dependence and inertia that may discourage innovation (Gärtner and Schön 2016; Bonvoisin et al. 2016) or increased assembly errors (AlGeddawy and ElMaraghy 2013), were not discussed in the context of CBPP. There is not enough evidence even to identify a tendency for or against these shortcomings. Last, this article did not address the cultural aspects of technology, for instance the acceptance or varying meanings of certain artifacts, shapes, processes, or functionalities (a treatise of the cultural and social aspects of CBPP technologies can be found in Giotitsas 2019).

5. Conclusion

Modularity is a fundamental aspect of digitalness. It has existed since the creation of ancient human-made artifacts; however, it is in the digital era that the division of human labor is increasingly infused with modularity. Much discussion has been taking place around new technology-focused buzzwords and concepts, arguably without paying enough attention to the organizational potentialities of modularity. CBPP exemplifies one of these potentialities.
CBPP presents dynamics that harness digital technologies by promoting non-coercive cooperation. CBPP questions the basic mainstream economics mantra that humans seek individual profit maximization when engaging in productive activities. It also challenges the conventional organizational structures of property-based, market-regulated organizations.

To take advantage of “clean” and more “inclusive” modularity, we need major institutional innovations that require tremendous political support both top-down and bottom-up. The CBPP communities are already here, so are the prefigurative forms of a new mode of production. If the goal is the deployment period of the digital revolution to be democratic, innovative, and environmentally sustainable, CBPP appears as a qualitative leap that could inspire policy-makers, scholars, and practitioners to build institutions for the deployment period and a new paradigm yet to come.

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