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Review

Patent Parasites: Non-Inventors Patenting Existing Open-Source Inventions in the 3-D Printing Technology Space

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Abstract: Open-source 3-D printing has played a pivotal role in revolutionizing the additive manufacturing (AM) landscape by making distributed manufacturing economic, democratizing access, and fostering far more rapid innovation than antiquated proprietary systems. Unfortunately, some 3-D printing manufacturing companies began deviating from open-source principles and violating licenses for the detriment of the community. To determine if a pattern has emerged of companies patenting clearly open-source innovations, this study presents three case studies from the three primary regions of open-source 3-D printing development (EU, U.S., and China) as well as three aspects of 3-D printing technology (AM materials, an open-source 3-D printer, and core open-source 3-D printing concepts used in most 3-D printers). The results of this review have shown that non-inventing entities, called patent parasites, are patenting open-source inventions already well-established in the open-source community and, in the most egregious cases, commercialized by one (or several) firm(s) at the time of the patent filing. Patent parasites are able to patent open-source innovations by using a different language, vague patent titles, and broad claims that encompass enormous swaths of widely diffused open-source innovation space. This practice poses a severe threat to innovation, and several approaches to irradicate the threat are discussed.

Keywords: 3-D printing; additive manufacturing; innovation; intellectual monopoly; intellectual property; open innovation; open hardware; open-source; patent; RepRap

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1. Introduction

Patents have long been hailed as a litmus test of innovation [1]. Most manufacturing companies use patents because they are expected to drive innovation [2] and improve firm financial performance [3]. In exchange for sharing the invention in the public domain, the firms then secure a 20-year monopoly on the patented materials, products, or processes [4,5]. Patenting, however, has come under progressively substantiative attack in the peer-reviewed literature for actually retarding innovation [6–12]. The software industry has shown a new path to innovation with the concept of free and open-source software (FOSS). FOSS is software that is released under a license that enables anyone to use, copy, study, and change it. In addition, it comes with the source code freely accessible so that everyone is encouraged to voluntarily improve the design of the code in exchange for the requirement that their adaptations must be re-shared with the same license [13]. Thus, FOSS sets up a gift economy [14], which has been well established to create rapid innovation [15,16]. The free and open-source innovation is based on widely used FOSS licenses [17], which have repeatedly [18] shown massive success [19]. To understand how ubiquitous FOSS now is, consider that it has become the dominant method of technical development in the software industry as a whole, where 90% of cloud servers run open-source operating systems [20] (including common household-named companies like Google, Facebook, Twitter, Yahoo, and Amazon) as well as 90% of the Fortune Global

500 (e.g., which includes both technology-based companies but also major retailers like Wal-Mart and even fast food enterprises like McDonalds) [21]. Today, all supercomputers run on open-source operating systems [22]. Open-source operates over 84% of the global smartphone market [23]. Similarly, more than 80% of the IOT (Internet of Things) market also runs on FOSS [24]. Lastly, all of the hype currently surrounding artificial intelligence (AI) also rests on an open-source foundation in AI [25,26]. More than half of academic articles on machine learning depend on open-source [27]. For example, Google open-sourced TensorFlow [28], which resulted in an era of fast-paced OS community-driven innovation that has directly contributed to the recent pace of incredible AI advancements [29]. The open-source innovation cycle was so fast that *The Guardian* reported on a Google engineer leak that said, "Open-source models are faster, more customizable, more private, and pound-for-pound more capable" [30].

With the rise of digital manufacturing, the same free and open-source development paradigm [31,32] has begun to infiltrate hardware and democratize manufacturing [33] of all kinds of physical products [34]. This parallel in hardware is known as free and open-source hardware (FOSH). The Open-Source Hardware Association defines open-source hardware [35] as follows:

> *Hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design. The hardware's source, the design from which it is made, is available in the preferred format for making modifications to it. Ideally, open source hardware uses readily-available components and materials, standard processes, open infrastructure, unrestricted content, and open-source design tools to maximize the ability of individuals to make and use hardware. Open source hardware gives people the freedom to control their technology while sharing knowledge and encouraging commerce through the open exchange of designs.*

Just like FOSS, FOSH uses viral licenses (e.g., CERN OHL [36]) that similarly require that if users make modifications or improvements in the hardware they are required to share their improvements with the global community with the same license [37]. Not surprisingly, FOSH has shown rapid innovation just like FOSS [38–40]. By graphing the instances of FOSS and FOSH showing up in the scientific peer-reviewed literature, it appears that FOSH is roughly 15 years behind FOSS in terms of technical development and uptake [41].

FOSH allows users to make exact replications of physical products from digital designs [42,43]. In addition, users can customize the designs and thus improve them for themselves [44], often using FOSS to do it [45]. When this is done with digital fabrication, what happens is that open-source designs generate wealth growth [46,47]. Thus, even the poor have access to high-value products like state-of-the-art scientific equipment [48–51] for little more than the processing electrical costs and some raw materials. This radically undercuts commercial or retail costs for products [52,53]. Researchers can expect to save about 87% compared to proprietary scientific tools [47]. There is one area where these savings are perhaps most stark—when 3-D printers are used [47]. For example, several studies have shown that using low-cost open-source 3-D printers can reduce the cost of mass-manufactured consumer goods, on average by 90–99% [54,55].

The recent application of FOSS and FOSH to rapid prototyping and additive manufacturing has democratized 3-D printing [56]. This is entirely due to the open-sourcing of the first self-replicating rapid prototyper (or RepRap) by Adrian Bowyer and the concomitant global 3-D printer hack-a-thon that drove massive innovation and 3-D printers into the common consciousness [57–60]. RepRap dramatically reduces additive manufacturing costs and has increased the number of FOSH 3-D printables exponentially [54], which now number in the millions. Having moved past first adopters, consumers are similarly saving themselves hundreds of millions of dollars by using FOSH 3-D printables and making their own products rather than buying them [61]. Open-source 3-D printing innovation primarily focused in the U.S., EU, and China is exemplified originally by Makerbot, as well as Lulzbot in the U.S., Prusa in the EU, and Creality in China, which consistently won *Make Magazine*'s annual 3-D printing shootout [62].

Open-source 3-D printing has played a pivotal role in revolutionizing the manufacturing landscape, democratizing access to cutting-edge technology, and fostering rapid innovation [56]. As the field has gained prominence, however, it has also encountered a range of challenges that threaten open-source principles. In his thought-provoking article, "*The state of open source in 3-D printing in 2023*", Josef Průša [63], a prominent figure in the industry, calls for an open discussion to protect the interests of the global 3-D printing community from these challenges. He noted that there is an uprise in 3-D printing manufacturing companies deviating from open-source principles, violating licenses, and, in the most extreme cases, patenting open-source technologies to the detriment of the community. The most pressing issue identified by Průša is the increasing number of companies applying for patents based on prior open-source developments. Such actions would be expected to hinder innovation, lead to financial burdens, and even result in lawsuits, all of which would hamper 3-D printing development that has been largely dependent on an open-source environment as shown above. This brings up a larger question: has a trend actually emerged of companies patenting clearly open-source innovations in the 3-D printing technical space?

To answer this question this study presents three case studies from the three primary regions of open-source 3-D printing development (EU, U.S., and China) as well as three aspects of 3-D printing technology. Specifically, this article evaluates the examples of recent patents in the 3-D printing space on additive manufacturing materials, a specific open-source 3-D printer, and core open-source 3-D printing concepts used in essentially all 3-D printers. The results are presented and discussed in the context of protecting open-source prior art and the rapid innovation it enables from being retarded by monopolistic control and hindrance to technological progress.

2. Methods

To evaluate Průša's claims, a case study methodology is presented, which compares the patents filed to obvious prior art in the existing open-source 3-D printing communities. Three case studies were selected to be (1) geographically diverse to cover inventions in the three major areas of open-source 3-D printing development (U.S., E.U., and China) and (2) cover the three main areas of open-source 3-D printing invention (3-D printing materials, 3-D printer design, and 3-D printer technologies applicable to many types of 3-D printers). Thus, from reviewing the recent literature and popular press, the three case studies that were selected to be evaluated include (1) an EU firm patenting the use of materials already in common use; (2) a U.S. government lab patenting an open-source 3-D printer design; and (3) a Chinese company patenting the basic building blocks of additive manufacturing that has long been in use in dozens of open-source 3-D printer designs.

2.1. Case Study 1: EU Firm Patenting Thermoplastics

Z Corporation is a 3-D printing manufacturing company founded in 1994 and is currently owned by 3D Systems (as of 2012). The company filed a patent for powdered 3-D printing materials for binder jetting/laser sintering type 3-D printing technology. The patent in question is EP1628823B1 (European patent office); it is also published as CN100553949C, WO2004113042A2, KR101120156B1, US7569273B2, KR101148770B1, JP4662942B2, and ES2376237T3 and is titled "Thermoplastic powder material system for appearance models from 3-D printing systems". This patent has a publication date of 26 October 2011 but a filing date of 19 May 2004, and the provisional U.S. application was first filed on 21 May 2003 [64,65]. This case study evaluates the similarities between the mentioned patent and the prior art or pre-existing similar materials widely used in 3-D printing before the patent was filed.

2.2. Case Study 2: A U.S. Government Lab Patenting a European Open-Source Hangprinter

UT Battelle a management contractor for the U.S. government's Oak Ridge National Laboratories filed the patent US11230032B2 titled "Cable-driven additive manufacturing system". The patent was filed on 12 April 2019 and was granted on 25 January 2022 [66]. This case study compares the similarities between the patent and prior art of the "Hangprinter" developed by a Swedish open-source inventor Torbjorn Ludvigsen. The inventor is a long-time RepRap builder and has raised funds to develop a suspended 3-D printing system that uses the ceiling and grounded anchors as a hanging frame for the 3-D printer. Since the printing system uses an unconventional frame, it can be scaled to build extremely large structures including houses. Torbjorn started the development of this printer in 2015, and since that time, hangprinters have been replicated all over the world, including in the U.S. [67].

2.3. Case Study 3: Bambu Lab, a Chinese Company Patenting the Basic Building Blocks of Additive Manufacturing

Bambu Lab is a company manufacturing desktop 3-D printers based in China. They have submitted patents for basic AM technologies. The parent company of Bambu Labs "Shenzhen Tuozhu Technology Co. Ltd. (Shenzhen, China) has filed at least 32 patents in China, which are discoverable on Google Patent searches, which resemble already existing open-source 3-D printing technology [68]. This case study dives into the details of three of these patents:

1. Patent no. CN114043726A (China): "Method and apparatus for 3D printing, storage medium, and program product", filed on 11 November 2021, current status—pending [69].
2. Patent no. CN114474738A (China): "A mechanism and 3D printing system that reloads for 3D printer" filed on 17 January 2022, current status—pending [70].
3. Patent no. CN216230793U: "Waste material wiping nozzle mechanism for 3D printer and 3D printer" filed 11 November 2021, granted 8 April 2022 [71].

3. Results

3.1. Case Study 1: Z Corp Patenting Thermoplastic Polymers for Powder-Based 3-D Printing

The patent filed by Z Corp in the U.S. and EU as well as other jurisdictions is titled "Thermoplastic powder material system for appearance models from 3-D printing systems", and the claims are about a powder adapted for 3-D printing and a method for using it [64]. The primary claim for the Z Corp patent is as follows: "A powder adapted for three-dimensional printing, the powder comprising: a loose and free-flowing particulate mixture comprising: at least 50% by weight of a thermoplastic particulate material selected from the group consisting of acetal polyoxymethylene, polylactide". This is remarkable as the second restricted material in the patent is polylactide or polylactic acid (PLA), which is the most common 3-D printing material in the open-source 3-D printing community [72]. Then, the first claim is extended with a broad list of many materials including "ethylene vinyl acetate, polyphenylene ether, ethylene-acrylic acid copolymer, polyether block amide, polyvinylidene fluoride, polyetherketone, polybutylene terephthalate, polyethylene terephthalate, polycyclohexylenemethylene terephthalate, polyphenylene sulfide, polythalamide, polymethylmethacrylate, polysulfones, polyethersulfones, polyphenylsulfones, polyacrylonitrile, poly(acrulonitrile-butadiene-styrene), polyamides, polystyrene, polyolefin, polyvinyl butyral, polycarbonate, polyvinyl chlorides, ethyl cellulose, cellulose acetate cellulose xanthate, and combinations, and copolymers thereof" [64]. This broad list obviously encompasses many commonly used 3-D printing materials. The effective date for determining novelty and obviousness is the initial U.S. provisional priority document in 2003, which is long after thermoplastics were used in 3-D printing (i.e., Stratasys systems that print thermos-polymers like poly(acrylonitrile-butadiene-styrene) (ABS) were commercialized in 1992). Thus, the patent-targeted materials were already in wide use for at least a decade in AM.

This patent could be used by the patent owner (that is, a 3-D printing manufacturing company) or sold sometime in the future to non-practicing entities (e.g., patent trolls) to limit the technical development of materials for 3-D printing. To prevent this from occurring, an open-source algorithm [73] has been developed to retain materials in the

3-D printing commons by obstructing (i) broad patent claims (e.g., the example list of thermoplastics in this case study), (ii) vague and generic claims (e.g., all organic materials or materials containing carbon), (iii) formulaic patent claims (e.g., in the example patent such as those covering both aqueous and non-aqueous fluids), and (iv) combinatorial claims (e.g., in case study patent "combinations or copolymers thereof"). The open-source 3-D printing material algorithm obstructs making obviousness clearer for patent examiners and lawyers because the idea (or so-called intellectual property) can be easily generated by a simple algorithm. For an example of the obviousness of prior art, let us consider a hypothetical situation of a material-constrained world where only three materials exist: sugar, cocoa, and peanut butter [73]. To make a candy product, a company cannot patent any combination of the mentioned materials as the material combination can be seen as obvious and thus non-patentable. Similarly, selecting from larger material options and patenting any material combinations falling under thermoplastic polymers for 3-D printing should not be allowed.

It is not clear if the publishing of the algorithm, which appeared in the peer-reviewed literature in 2015, can protect the materials commons retroactively (or even in the future), and efforts have been made to implement it in Python and run it [74]. Unfortunately, this takes a substantive amount of computing power and, as of now, such algorithms or even AI are not able to generate inventions that can be protected by patents [75].

3.2. Case Study 2: Department of Energy Patenting the Open-Source Hangprinter

The hangprinter [67] is an open-source cable-driven RepRap first invented by Torbjorn Ludvigsen and documented in great detail in a blog that started in 2014 [76]. The news about the development of a frameless printer (hangprinter) developed by Ludvigsen, including pictures of the hangprinter printing an artistic depiction of the biblical Babel tower (Genesis 11:1–9), as shown in Figure 1, was published in all of the major 3-D printing blog websites in March 2017, including fabbaloo.com [77], 3dprintingindustry.com [78], 3dprint.com [79], all3dp.com [80], 3dnatives.com [81], and archdaily.com [82]. It is clear from the completed print (see Figure 2) that one of the obvious applications of the hangprinter is to be used for construction. There it is building a mini-replica of a building more than one story tall. To be able to make a building of any size one would simply need to anchor the hangprinter from something above the height of the building one would want to construct and then 3-D print with appropriate materials. In conventional building practice, when materials need to be moved to the top of a building under construction, cranes are generally used for tall buildings and cherry pickers for small ones, making the use of a hangprinter with cranes or cherry pickers obvious to anyone familiar with the hangprinter and basic construction practices.

Figure 1. Hangprinter in operation printing a Babel tower. Reprinted under Gnu Free Documentation License by Torbjørns from Ref. [83].

Figure 2. The open-source hangprinter being used to construct a multi-story building model. Reprinted under Gnu Free Documentation License by Torbjørns from Ref. [83].

UT-Battelle, LLC, contractor to Oak Ridge National Laboratory run by the Department of Energy in the U.S., filed a patent under the name "Cable-driven additive manufacturing system" to patent the idea of using a hangprinter for construction (see Figure 3).

As this appeared to be the use of government funds to patent an invention developed by an inventor in the EU, there was some concern that the patent owners would attempt to stifle hangprinter development. The inventor of the hangprinter, Torbjorn Ludvigsen, published a blog criticizing the patent [76]. He argued that the patent in question is highly similar to the hangprinter, a 3-D printing technology that already existed before the filing of the patent, and he provided dozens of links to prior art he and other open-source collaborators had posted openly. The hangprinter project was four years old at the time the patent was filed and had a substantial amount of publicly available prior art, including technical blog posts, forum posts, YouTube videos, Tweets, newsletters, Wiki articles, and more.

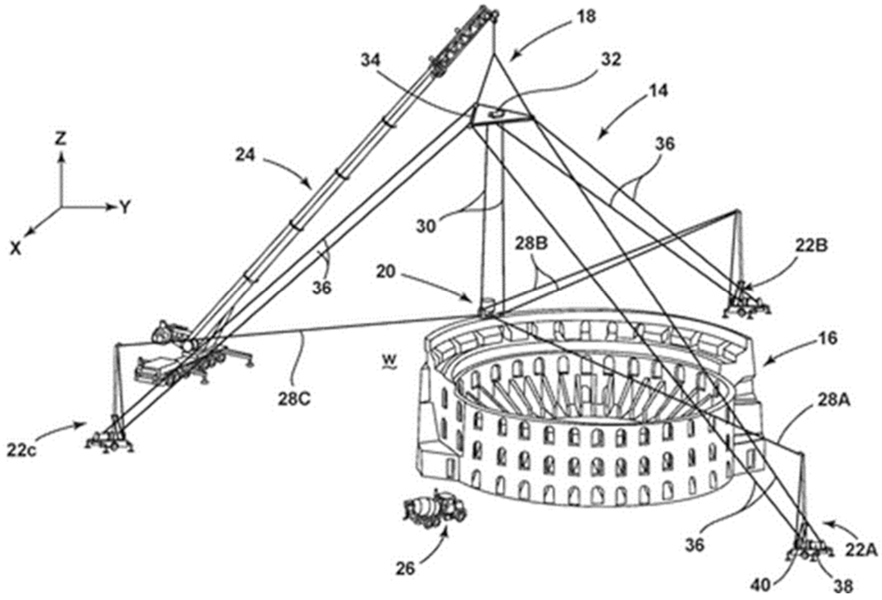

Figure 3. The schematic shows a circular structure with outer walls being 3-D printed by a cable-driven parallel robot with four cable directions including one near vertical one. This is an actual figure from the patent in question [66], which could possibly be the start of a Babel tower, which would make even the example use case unoriginal.

Interestingly, the patent [66] makes only two references to the hangprinter, which are insufficient to reveal how deeply similar the filed patent was to the open-source hangprinter. The references include an English Wikipedia article [84] and an outdated article from 3ders.org [85]. According to the inventor, this does not cover the wealth of information available on the open-source hangprinter that would demonstrate the similarity between the two systems, which appears to have been ignored by U.S. patent examiners. It appears clear from comparing Figures 1–3 that the patent resembles the most widely published press images of the hangprinter from 2017. The device has the anchors lifted above the ground by thin tall structures, and the end effectors are held in place by pairs of parallel cables. The schematic is very similar to the photos (Figures 2 and 3) published by Torbjorn in his blog showing a version of the hangprinter in operation, which was published a year before the patent was filed. The schematic is most similar to the video blog published by the creator of the open-source printer in April 2017 [86]. There is thus substantial evidence that a U.S. government-funded research institute patented an invention that was not only open-source and widely known but that they found the technology on Facebook. The U.S. Patent Office says that a patent will not be issued "if the differences between the claimed invention and the prior art are such that the claimed invention as a whole would have been obvious before the effective filing date of the claimed invention to a person having ordinary skill in the art to which the claimed invention pertains"[87].

3.3. Case Study 3: Comparing Patents Filed by Bambu Lab to the Already Existing Open-Source Technology

The following three sub-case studies are all filed by Bambu Lab in China.

3.3.1. Patent No. CN114043726A: "Method and Apparatus for 3D Printing, Storage Medium, and Program Product"

Multi-height or adaptive slicing for 3-D printing has been demonstrated by scientific and open-source maker communities long before 2021. For example, the goal of adaptive slicing is to find an optimal balance between fabrication time (number of layers) and surface quality (geometric deviation error), and a 2019 scientific article [88] illustrates the slicing method. The authors propose an algorithm that uses a "metric profile", which is a measure of the geometry error distribution along a given building direction, to efficiently generate globally optimal slicing plans. Figure 4 shows the results of the adaptive slicing where the 3-D model is sliced with different layer heights according to the details of the surface features present on the model. This description of slicing is actually superior to the simple option of multi-height slicing being instituted manually by a user.

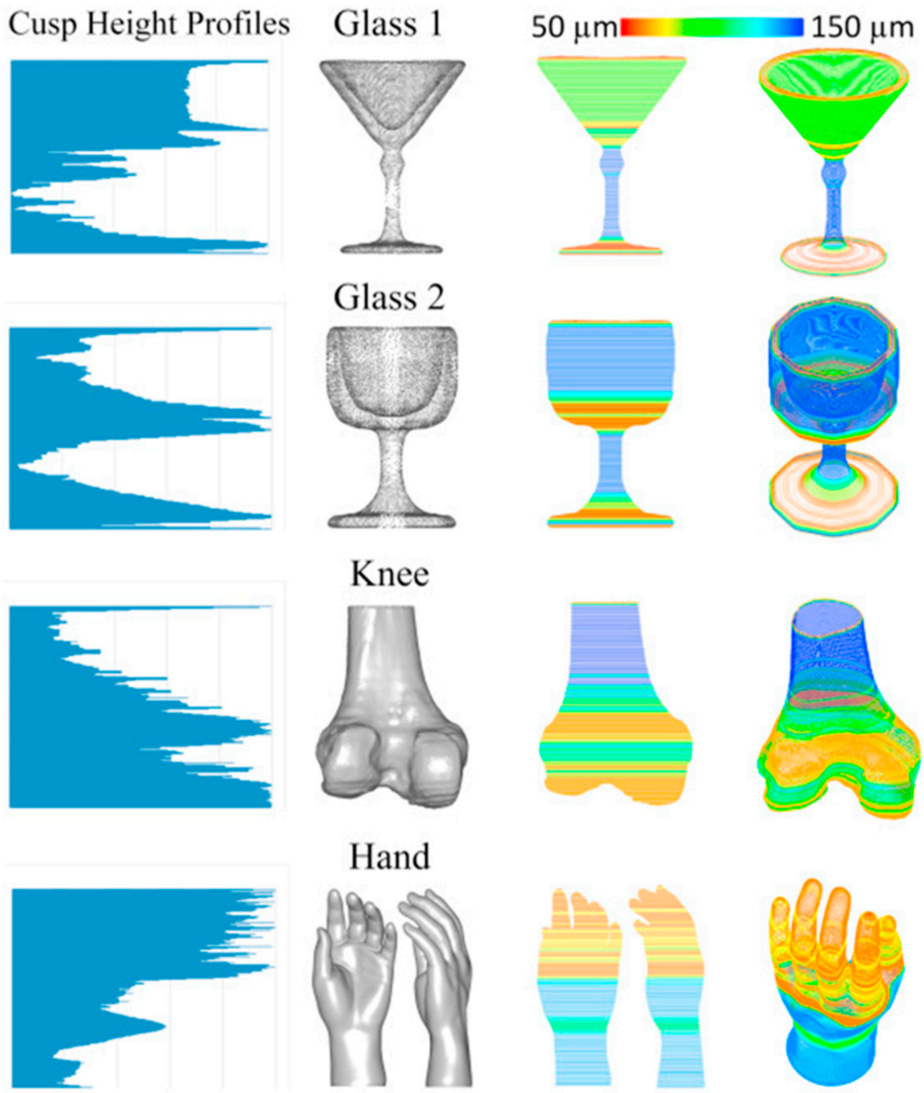

Figure 4. Results of adaptive layer slicing [88].

Multi-height slicing (or adaptive layer height slicing) had also already been incorporated and demonstrated in free and open-source slicers such as PrusaSlicer [89], which anyone in the world could have downloaded prior to 2021. The feature was introduced in the PrusaSlicer in 2020, where it allowed users to either use the automatic adaptive slicing performed by the slicer software itself based on the feature details of the 3-D model or let users manually select the layers. Figure 5 shows the slicing of a model with the "adaptive" variable layer height enabled in PrusaSlicer.

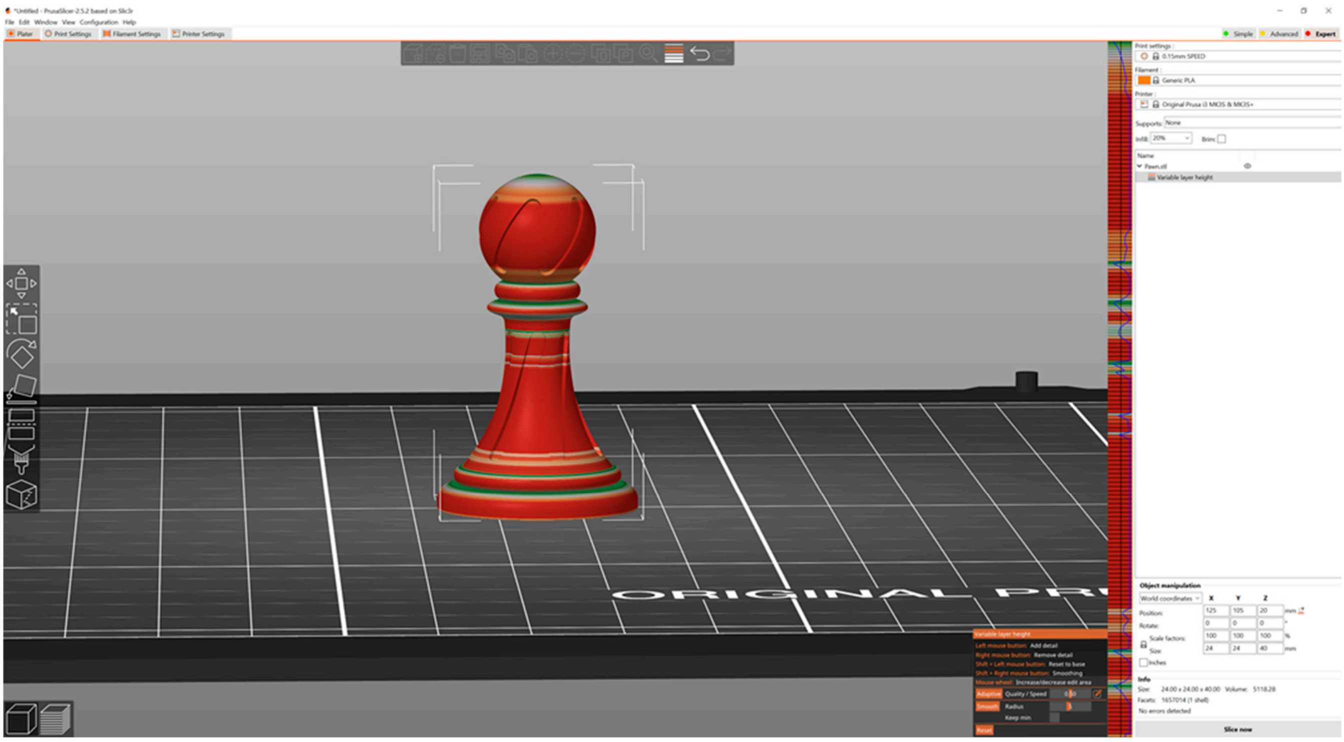

Figure 5. Variable layer height settings in PrusaSlicer, a free and open-source slicing software.

Figure 6 shows the schematic for the patent [69], which has claims that describe a method for the multi-height slicing of a 3-D model during the 3-D printing process. The method involves dividing the model into slices along its height, where slices within specific precise portions of the model have a smaller layer height compared to slices outside those portions. This allows for more precise control and resolution in areas that require it while maintaining a higher layer height for other parts of the model. The slicing is performed based on the positional relationship with boundary boxes created around the precise portions. The resulting multi-height slices are then processed further, including merging slice regions within the precise portions, generating control code, and adjusting printing parameters accordingly. The vague title of the patent does not point towards the claims made in the broad patent description. This makes the filed patent difficult to find and decipher or to register a complaint to the patent office. This is important because obfuscating the actual invention of the claims by using a title that means nothing makes monitoring for infringement on widespread open-source inventions extremely challenging. The patent was filed in November 2021. Thus, it appears clear that in this case, a firm simply patented a concept that was not only available in the peer-reviewed literature and already in widespread use by tens of thousands of hobbyists, but was also provided free of charge by a commercial rival in their open-source software.

3.3.2. Patent No. CN114474738A: "A Mechanism and 3D Printing System That Reloads for 3D Printer"

Although there are many applications of single-material (color) 3-D printing, there have been multiple attempts in the open-source community to enable multi-material 3-D printing [90–93]. In addition, this feature was implemented by Prusa 3-D printers with the open-source MMU2.0 upgrade introduced in 2018 [94,95]. The open-source MMU 2.0 (Figure 7) includes a motorized selector head with a filament sensor. This head can handle up to five different materials simultaneously. It uses a direct-drive feed system, which simplifies filament loading and reduces sensitivity to filament quality. The selector head also incorporates an automated filament-cutting blade to prevent jams and improve reliability. To control the open-source MMU 2.0, there are physical buttons for manual operations. Users can easily move the selector head and load/unload filaments with these buttons. The device also features status LEDs for clear visual feedback.

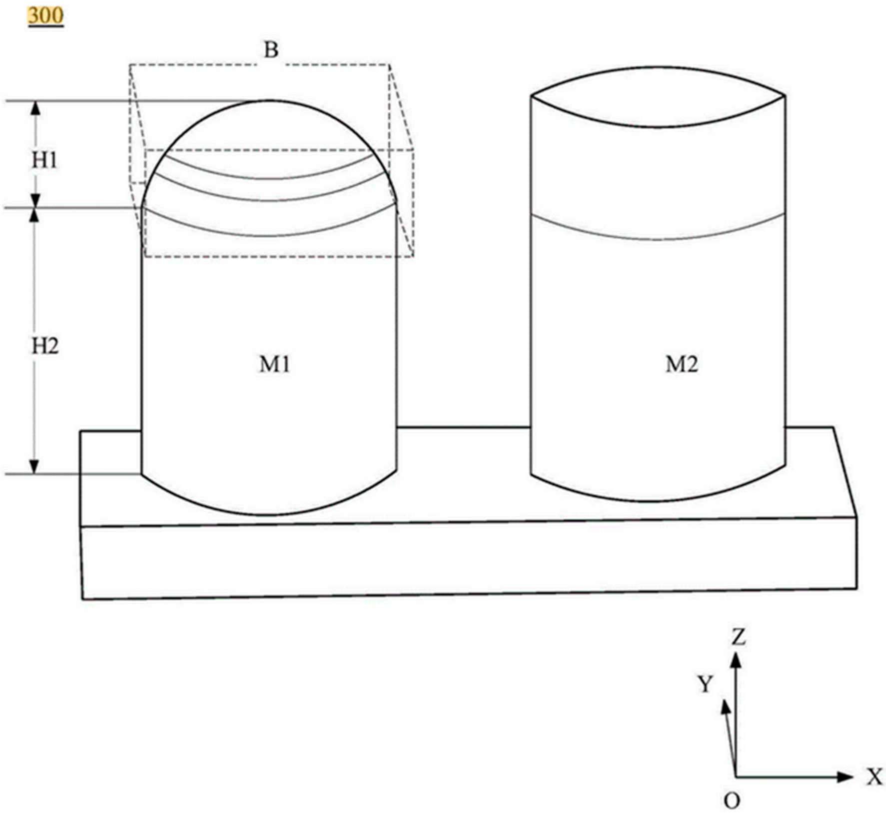

Figure 6. Schematic of the multi-height slicing patent shown in B area [69].

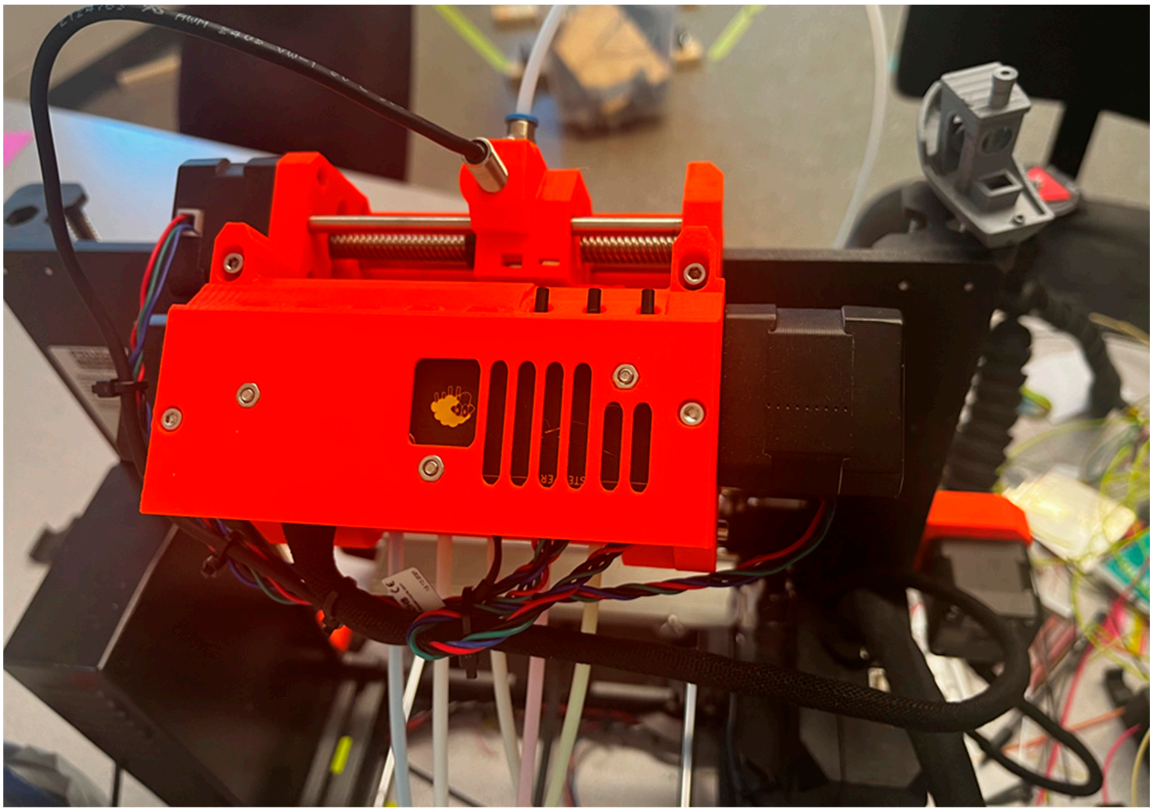

Figure 7. MMU2.0 material selector installed on a Prusa i3 MKS3.

The open-source MMU 2.0 integrates seamlessly with Prusa printers (Figure 8), functioning as a single unit. Printing with the MMU 2.0 is similar to standard printing on a Prusa printer. The user prepares the model, generates the G-code using software like Slic3r PE, and initiates printing. The MMU 2.0 handles material switching automatically during the printing process. Again, similar to case study 3.1, an open-source device was not only widespread on the internet before the patent submission but a business competitor had already commercialized the concept and released all the hardware, firmware, and software under open-source licenses prior to the submission of the patent.

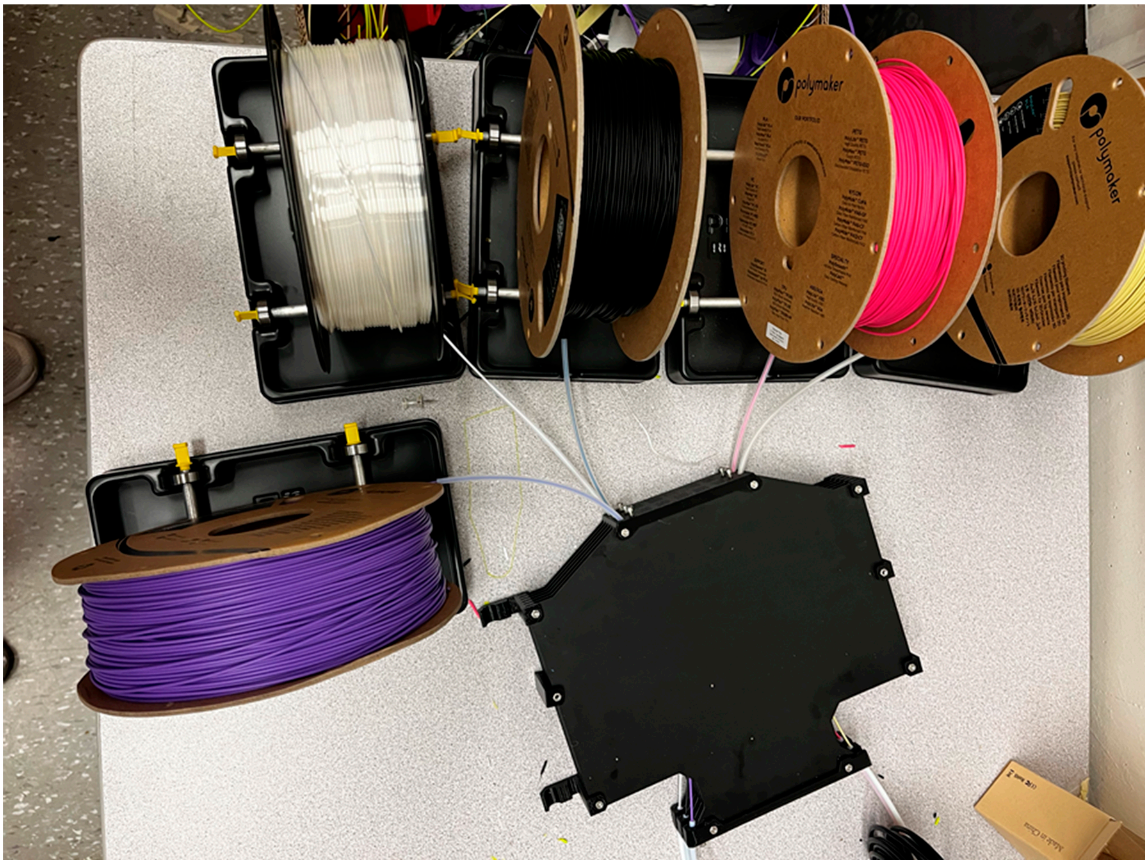

Figure 8. MMU2.0 upgrade material feeding system attached to Prusa i3 MK3S.

Several years after multi-material printing was common and commercialized by an open-source 3-D printing company, a Bambu Lab patent [70] was filed that describes a device used in a 3-D printer for continuous material reloading and color changing. The device included a base, a guide system, a slide unit system, and a feeding mechanism. This device enables a continuous material supply, material change, and color change during 3-D printing. It enhances the continuity of the printing process and allows for the completion of multi-color or multi-material printing tasks. Figure 9 shows the mechanism of hosting multiple filament spools for a multi-material/multi-color 3-D printing system. The mechanism is used in combination with the FFF-based 3-D printer, which allows the printer to switch between materials or colors.

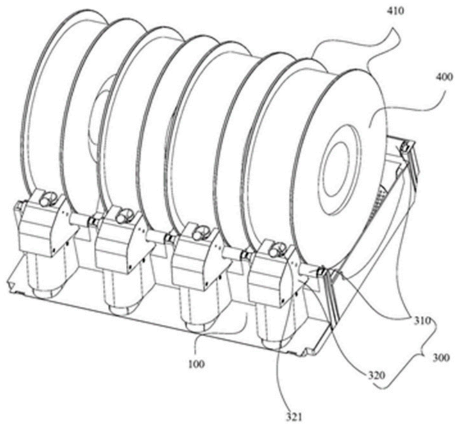

Figure 9. Schematic of the multi-material system patent [70].

3.3.3. Patent No. CN216230793U: "Waste Material Wiping Nozzle Mechanism for 3D Printer and 3D Printer"

The open-source 3-D printing community has always been plagued by the tediousness of cleaning the 3-D printer nozzle every time before starting the print. To solve this problem, the community has come up with designs ranging from a simple wire brush attached to the printer frame [96–98] to automated gear-based rotating brushes to clean the nozzle [99–101]. The process works by attaching the cleaning media to the printer and modifying the G-code to move the nozzle over the cleaning media. These ideas, again, have been in widespread circulation in the RepRap community.

In addition to the concept of nozzle cleaning already being well-established in the community, this method has also been incorporated in commercial open-source 3-D printers. Fargo Additive Manufacturing (FAME 3D, located in Fargo, ND, USA) has been including the nozzle wiping mechanism in their 3-D printers starting from Lulzbot TAZ 6 and Lulzbot Mini 2, which debuted in the year 2019 [102]. The mechanism includes a felt pad attached to the print bed where the nozzle brushes itself before starting a new print with the help of a modified G-code. Figure 10 shows the nozzle wiping mechanism included with the Lulzbot TAZ 6 3-D printer. Interestingly, in true RepRap fashion, the plastic component that holds the felt pad down itself is 3-D printed and all the Lulzbot design files and software are free, open-source, and readily available.

A Bambu Lab patent filed in 2021 [71] describes a mechanism used in a 3-D printer to clean the nozzle and get rid of the waste material. It includes a groove where the waste material can fall into and a sliding part that moves back and forth on top of the groove—just like the process illustrated in Figure 10. When the printer's tool head pushes against it, the sliding part moves forward, and when it moves back, it pushes the waste material out of the groove. The shape of the groove helps guide the waste material [71].

Again, similar to cases 3.1 and 3.2, Bambu Lab simply patented a known technology in the open-source community, which was readily available from a commercial rival. It should be pointed out that these oversights by the Chinese patent system and Bambu Lab appear not to be anomalies but a pattern. Bambu simply patents (in China) inventions made by others after they have been established in the global open-source community for several years. Apart from the examples mentioned above, other well-known open-source-related innovations have been patented in China. For example, the rechargeable spool for 3-D printing filament [103] was already available as an open-source community design on the 3-D printing repository thingiverse.com [104]. A patent has been filed for a "vibration actuator providing vibratory motion to the printhead [105]", which is nothing but a modification of the open-source firmware to modify the G-code. This feature has been already implemented in the PrusaSilcer as a "Fuzzy Skin" texture [106]. Another patent was filed for including a camera to monitor the print quality [107]; this had been already proved in a peer-reviewed article two years earlier, which released all of the source code to do it with open-source licenses [108]. A patent for an "intelligent 3D printing platform" based on a polar coordinate system was filed in 2020 [109], yet a 3-D printer based on a polar coordinate system was demonstrated in 2017 [110]. A trivial patent was filed for an adjustable display for controlling the 3-D printer [111], yet many open-source 3-D printers have this feature. For example, Creality 3D offered a modular touchscreen panel as an upgrade kit [112]. There is clearly a trend of obvious, well-dispersed 3-D printing innovations already in the open-source ecosystem being patented in China.

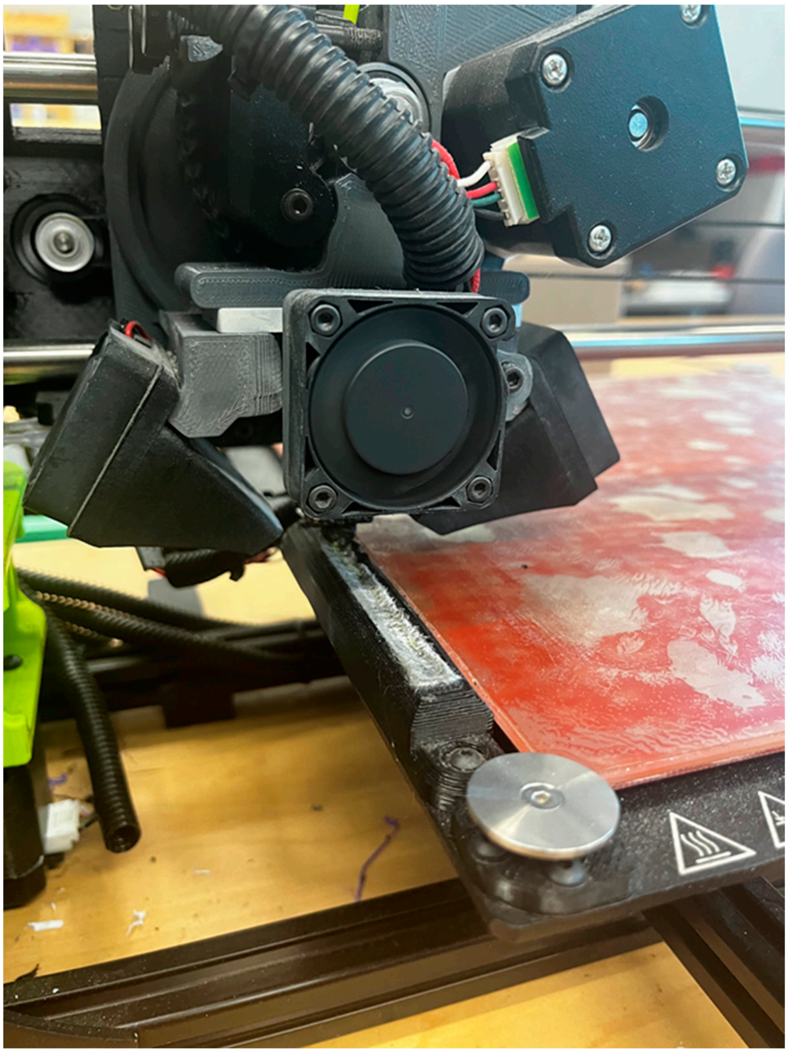

Figure 10. Lulzbot nozzle wiping/cleaning system.

4. Discussion

In nature, a parasite is a creature that lives off of an organism of another species, known as the host, and gets its food from or at the expense of its host [113]. In the intellectual property ecosystem, Heled argued that patent trolls (non-practicing entities) may be better understood when viewed as analogous to these biological parasites [114]. In the examples reviewed in this article, however, more often than not those patenting open-source inventions were not patent trolls but instead active 3-D printing manufacturing companies. These companies are better examples of *patent parasites* as they can kill their host. Thus, in the context of this article, the open-source 3-D printing community is the host providing nourishment to patent parasite companies that extract IP (food) from the community and patent it to the detriment of the host community. In the open-source community, there has always been some degree of freeloading [115], but this did not directly harm the community and did not become parasitic as freeloaders generally only hurt themselves by not having others build on their specific technologies because of the lack of resharing to the community [116].

With the example case studies reviewed here, a new form of *patent parasitism* appears to be on the rise in the 3-D printing technology space. The most common method observed in the case studies involves (1) letting the open-source community innovate and develop a technical solution, (2) waiting until that innovation has been widely tested by the open-source community and in some cases even commercialized by an open-source firm, and (3) surreptitiously patenting the technology by hiding the core ideas in the claims while using a vague (and sometimes irrelevant) patent title and abstract to obfuscate any attempts for the open-source community to police it. In the worst examples exemplified by cases 3.1, 3.2, and 3.3, this is done in another language in a clearly lax patent office (China) that fails to do due diligence in searching for obvious prior art in English. If these patents are weaponized either by the firms that invested in them or by non-practicing entities that purchase the patents, the vibrancy of open-source 3-D printing technology first founded in the RepRap project could be crippled. As Průša mentions in his article [63], patent trolls pose a formidable challenge. These entities, often non-practicing organizations, exploit patent rights beyond their actual value, stifling innovation and forcing companies to engage in legal battles. The rise of patents related to 3-D printing further exacerbates the situation, creating a potential roadblock to technical progress and inhibiting the growth of 3-D printing for another two decades. Patent parasites that simply patent existing open-source technologies are potentially an even greater threat than patent trolls as they directly attack the goodwill so effective at driving innovation in the open-source paradigm.

In the recent response [117] to the article by Průša [63], the CEO of Bambu Lab presented their perspective on the role of patents in the 3-D printing industry. He acknowledged the challenges of taking a design into production, particularly in light of supply chain issues, and recognized the significant role of Creality by producing a product like the open-source Ender 3 in bringing down the costs of desktop 3-D printers. His assertion that they will not use patents as obstacles for other innovators and that they will not employ overly broad patent claims that hinder the development of the industry is commendable. However, the reality of their actions made clear in the results of this study, particularly in China, seems to contradict this statement. Worse, even if Dr. Tao (Spaghetti Monster) is honorable, Bambu Lab's next CEO, or the company that buys the patents, may not hold these ideals, which threatens the entire industry. The fact that the results of this study have shown that companies are applying for patents that simply copy already existing open-source technologies makes such companies appear incompetent at best (e.g., maybe their engineers are simply unaware they could simply download the plans for any of the inventions detailed in case studies 3.1–3.3) and malicious at worst (e.g., if they attempt to use their patents to drive smaller firms out of the market in the future). It is well-established in the literature reviewed in the introduction that the industry and customers will benefit from competition made possible by the open-source paradigm. However, if they are patenting open-source technology that made this competition possible in the first place, firms are potentially crippling their competitors and undermining the very essence of the open-source ethos.

There are still clear issues with patenting existing open-source technologies (as clearly demonstrated in the results), which should not be possible anyway. These issues include the following:

- Inhibiting innovation and slowing development: Patenting already existing open-source technology can hinder innovation by restricting the free flow of ideas and limiting the ability of others to build upon existing knowledge. It could stifle creativity and impede the collaborative nature of the vibrant innovative open-source community. This can hinder the pace of innovation and delay the benefits that open-source 3-D printing can bring to various industries including science [44,48–50,52,53,118,119] and medical technology [120–122] and reaching sustainable development goals [123–125].

For example, new firms may have been unwilling to enter into the construction field with hangprinters because of the patent detailed in the second case study.

- Encouraging monopolies: Granting patents for already existing open-source technology could lead to the creation of IP monopolies [126,127] as companies with patents can control and exclude others from using or improving the technology. This can reduce competition, limit consumer choice, and drive up prices to the detriment of consumers (and in this case, prosumers). For example, multi-material 3-D printing could be brought to a halt in China for all but one company if the patents detailed in the third case study are considered valid.
- Patent thickets: If multiple companies use the patent parasite approach, the patenting of open-source technology could result in patent thickets, where numerous overlapping patents exist for the same or similar technologies. Patent thickets are well-known to create legal complexities, increase the risk of patent infringement lawsuits, and impede progress by making it difficult for innovators to navigate the patent landscape [128,129]. A well-known patent thicket [130] that has stifled modern technology is found in nanotechnology [131,132], which has become so pernicious as to be called a modern "intellectual property tragedy" [133]. An obvious solution is to make nanotechnology open-source for the betterment (and even greater commercial success) of the technological community [134], which provides all the more reason not to patent existing open-source technologies in the AM space. Similarly, a patent thicket would clearly stifle innovation in the 3-D printing industry if many firms claim common 3-D printing materials as was done by one firm in the first case study. The resultant legal morass would not be expected to improve the technology at all but would raise costs for consumers for firms needing to fight lawsuits.

Patents are obviously not necessary for providing legal protection. Alternative protection mechanisms including open-source licenses, such as copyleft licenses (e.g., GNU the General Public License, and CERN Open Hardware Licenses), already provide a framework for protecting open-source technology while maintaining its open nature. These licenses ensure that derivative works also remain open source, promoting collaboration and preventing proprietary control. To work as protective instruments, they need to be used within the legal system, and far more work is needed in this area.

It is clear from this review that many 3-D printing technologies under current legal patent protection have already been implemented in commercial products or published in the open-source domain by the open-source hardware community. These patents are theoretically invalid but need to be invalidated legally as they threaten the entire innovation system in the AM space. In addition, to counter future threats, the community must establish a defensive fortress of "prior art" and leverage innovative approaches to protect the basic building block innovations of 3-D printing. To combat these threats, Průša emphasizes the importance of community participation. To tackle this, the existing knowledge, designs, and innovations need to be actively documented in the public domain under open-source licenses. By doing so, the open-source 3-D printing community can create a repository of prior art that serves as evidence of pre-existing technology and ideas. These can then be used as a defense against patent claims by demonstrating that the claimed inventions are not novel or non-obvious. Helpful innovative approaches can include developing algorithms or software tools that help identify prior art related to 3-D printing materials, techniques, or processes. By leveraging such tools, the community can proactively challenge copycat patents and contribute to a stronger defense against patent trolls and non-innovative patent claims. By actively sharing ideas, innovations, and contributions through various channels such as open-source repositories, project platforms, and social media, the community can fortify the public domain and make ideas easily discoverable as prior art. There have been some efforts to do this with the Open Source Hardware Association's (OSHWA's) open hardware certification process [135] and quasi-automate this process for MediaWiki websites like Appropedia [136]. Clearly, far more work is needed to aggregate all of the current open-source inventions and to add the OSHWA's certification database to the official list of repositories that are checked by all patent offices for prior art.

5. Conclusions

This review presents three case studies from the EU, U.S., and China to evaluate innovation in the 3-D printing industry. The results of this review of inventions in the 3-D printing industry have shown that non-inventing entities throughout the world are attempting to patent/are patenting clearly open-source inventions already well-established in the open-source community and in the most egregious cases commercialized by one (or several) firm(s) at the time of the patent filing. There is substantial evidence of companies, including a U.S. government-funded research institute, patenting inventions that are not only pre-existing/prior art but also have been developed and used by the open-source 3-D printing community.

There seems to be a particularly anti-competitive and anti-innovation trend, which is dubbed patent parasitism here, of companies in China patenting open-source innovations in the 3-D printing industry by using a different language with vague patent titles and broad claims that encompass enormous swaths of widely diffused open-source innovation space. This practice could hinder innovations when (1) innovators believe that an open-source concept is under a patent that demands a license to use and (2) open-source firms, which specifically avoided patents in part to avoid IP lawyer investments, must defend their own work from IP lockdown, with lawsuits. There appears to be a clear threat that if the patenting of open-source technologies continues, particularly with the threat of AI-generated patent parasites, competition from open-source community-supported firms could be stifled, which would inhibit innovation both in the commercial and community space. Unfortunately, until the global patent system is modernized to include the reality of more rapid innovation provided by an open-source paradigm, the patent system will continue to miss prior art and issue bogus patents. It thus appears that, in the short-term at least, the open-source community needs to be vigilant in protecting its innovations stolen by patent parasites.

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