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Open Hardware Licences: parallels and contrasts

Open Science Monitor Case Study

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Acknowledgements

1   Introduction

Under the umbrella of "Open Science," technical and scientific practices are currently expanding the principles of openness and collaborative development from Free and Open Source Software (FOSS) projects to physical artefacts. Research laboratories have, for example, embraced "Open Hardware" (OH) as a fruitful model for collaborative and flexible development of instruments and infrastructures for experimental purposes (Pearce, 2012). OH is becoming an important model for increased accessibility, transparency, and openness in scientific and educational practices (Murillo, Molloy and Dosemagen, 2018).

Open Hardware (or "Open Source Hardware") is a term for any technical artefact—machines, devices, three-dimensional objects, or any other physical object—whose design is made publicly available through open licences which specify the freedoms a licensee can exercise in studying, modifying, distributing, making, and commercializing the hardware. OH projects have as a common goal the creation of a culture of hardware sharing. In the past two decades, other terms have been used to promote similar goals, such as "open design" and "open hardware design" (West and Kuk, 2016). The most enduring efforts, however, emerged in the past decade with the creation of robust scientific projects, community associations, academic journals, conferences, and businesses that are primarily dedicated to OH worldwide.

One of the main differences between OH and FOSS consists in the nature of the design process, which implies building physical artefacts at non-negligible costs. While the costs of reproducing software are marginal or tend to zero, hardware producers need to invest in manufacturing in the prototyping and development phases. Katz (2012) describes this difference in terms of a spectrum of non-rival and rival goods: from software-related aspects (such as design files, programmable logic cores, firmware code, and technical documentation) to physical instantiations in hardware (such as circuit boards, programmable chips, mechanical assemblies, and 3D objects).

Another important difference consists in the legal foundations of OH licences: they present us with a higher level of complexity in comparison with FOSS ones. In this case study, we examine the implications of OH licensing with the description of the four most relevant licences in current use. We describe the differences between OH and FOSS licensing to discuss the promises and challenges of creating and fostering a culture of hardware sharing. We conduct our analysis with the assumption that open licences constitute primarily a "social contract" (Coleman, 2013; Kelty, 2008; Weber, 2004): they describe conditions, obligations, constraints, and moral orientations for the public circulation of design documentation. For the conclusion, we discuss open issues in open licensing, broader implications, and offer policy recommendations for OH adoption.

1   Background

Open Hardware is a recent phenomenon of the past decade (Bonvoisin et al., 2017), yet it has already enabled educational programmes (Heradio et al., 2018), research infrastructures (European Commission 2019; Murillo and Kauttu, 2017; Serrano et al., 2009), and a diverse range of commercial applications (Balka et al. 2009; Howard et al., 2012). Hardware sharing communities can be found in several domains of technical and scientific endeavour, such as: interaction design, electronics prototyping, large-scale research infrastructures, laboratory science, and electronics education with a particularly strong presence in community spaces that are dedicated to small-scale fabrication, self-training, and repurposing of existing technologies, such as makerspaces, hackerspaces, and fabrication laboratories (Gibb, 2014; Lallement, 2015; Walter-Herrmann and Büching, 2013). Remarkable projects with global influence include the electronics prototyping platform Arduino (arduino.cc); network technologies for precise and accurate time distribution (Pujol, Wareham and Murillo, 2019; Murillo, 2018; Serrano et al., 2009); and RepRap (reprap.org), a collaborative 3D printing community (Pearce, 2012; Söderberg,

2013; Boujut, 2015). In the CERN Open Hardware Repository (ohwr.org), for instance, the largest repository for control engineers in research organizations, there are more than 300 registered OH projects (Pujol, Wareham and Murillo, 2019). OH projects exhibit different degrees of complexity and inventiveness, spanning across various industries and ranging from large-scale systems to simple hobbyist technologies for educational purposes.

Despite substantial differences in terms of complexity, scale, and expertise that is required from contributors, OH projects have in common the practice of publishing documentation and source files for replication purposes. This practice is governed through open licences that allow any individual or organisation to reproduce or modify the hardware, as well as to redistribute the design files so that licensees can improve, modify, add features, or fix bugs. In the past decade, Creative Commons licences have been widely used by OH distribution companies, however, the legal provisions for open licensing of copyrightable materials (such software) does not apply quite so straightforwardly to hardware. In addition to copyright licences, OH licences typically include clauses involving patents, industrial design, and trademarks. One of the basic differences relies on the fact that the outputs of an OH project are: "(1) the documentation that reflects the design, and from which one may manufacture the product; and (2) the products that are, in fact, manufactured from that documentation" (Ackermann, 2009, p. 192). These two outputs are covered by distinct branches of intellectual property (IP), such as copyright, patents, trademarks, and industrial design, but may also be covered by contractual stipulations. The current debate in OH licensing highlights the challenges of scope, enforcement, and liability, since legal matters involving hardware sharing are far from settled (Greenbaum, 2012; Katz, 2012; Beldiman, 2018; Beldiman and Fluechter, 2019).

In the next section, we will describe the most relevant open licences with a focus on their provisions for hardware sharing. Our goal is to demonstrate the promises and challenges of extending FOSS licensing provisions to the domain of hardware.

2   Open licences and definitions

Open licences[1] express the moral and legal sensibilities of technical and scientific expert communities: they are often drafted by technologists themselves in collaboration with legal experts. OH licensing is particularly relevant because its novelty does not reside solely on legal provisions for sharing rival, physical goods, but rather in the technical, institutional, and social dynamics that it enables to create viable alternatives to restrictive IP-based technology transfer.

The practice of circulating engineering drawings has a much longer genealogy that predates "open innovation" practices (Chesbrough, 2011; Chesbrough et al., 2014; Hippel, 2005). It has involved engineering communities in various national contexts since the advent of popular radio applications in the early 20th century (Ackermann, 2009; Dunbar-Hester, 2014; Murillo, 2015). In this context, OH licensing presents us with new legal and sociotechnical challenges: it is not limited to lateral and informal sharing, examined in the literature on "open design" and "user-led innovation" (Von Hippel 1986), but fundamentally about the general conditions for replicating entire hardware projects.

Open Hardware licences have historical precursors in Free and Open Source Software licences and community definitions. They derived from legal provisions first elaborated in the context of FOSS development communities (Ackermann, 2009; Katz, 2012; Beldiman, 2018). In the past decade, open licences have been widely used by hardware distribution companies (in various countries of the European Union as well as in China and United States) and early certification programmes have been created in the United States (in the context of the "Software in Public Interest", a non-profit organisation created in 1997) and

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[1] The legal scholar Dana Beldiman (2018) provides us with a very useful definition: "the open licence agreement is a privately ordered, contractual instrument with a dual role. On the one hand, it governs the community and ensures its cohesion and collaborative, non-competitive spirit. On the other, it allocates IP rights and permissions relating to the knowledge generated among contracting parties, i.e., to members of the community" (p. 37).

in Europe by a group of engineers, scholars, and FOSS activists around the "Open Hardware and Design Alliance" (OHANDA) in 2008, which was unfortunately discontinued (Powell, 2012) but resurfaced with the "Open Source Hardware Certification" programme of the Open Source Hardware Association in 2018.

In 2010, the event "Opening hardware: a workshop on legal tools" at the design studio Eyebeam in New York brought together legal experts from Creative Commons, OH engineers and interaction designers to discuss the possibility of using Creative Commons licences for hardware sharing (Gibb and Mota, 2013). This gathering proved to be one of the key moments for mobilising the original group that would bootstrap the drafting process for the "Open Source Hardware Definition," a collective document that was directly inspired in the well-established "Open Source Definition" for software (Perens 2001) and vetted by an international group of hardware designers and enthusiasts.

Open Source Definition (v. 1.9)	Open Source Hardware Definition (v. 1.0)
Source code	**1. Documentation**
	2. Scope
	3. Necessary software
Derived works	4. Derived works
Free distribution	5. Free redistribution
Integrity of the author's source code	**6. Attribution**
No discrimination against persons or groups	7. No discrimination against persons or groups
No discrimination against fields of endeavor	8. No discrimination against fields of endeavor
Distribution of license	9. Distribution of license
License must not be specific to a product	10. License must not be specific to a product
License must not restrict other software	11. License must not restrict other **hardware** or software
License must be technology-neutral	12. License must be technology-neutral

Table 1. Comparison between Open Source definitions for software and hardware.

The Open Source Hardware Definition introduced key changes to account for the differences between hardware and software. The first consists in the elaboration on the notion of "(1) documentation," which expresses the community understanding that hardware can only be open if it is sufficiently documented and publicly accessible. The notion of "(2) scope" describes which parts of any given hardware design are covered. The third item, "(3) necessary software," specifies that embedded software must be open source and interfaces must be sufficiently documented. The term "source code" in the original software definition is substituted by these three items to account for the distinctive elements that constitute hardware sources (such as engineering drawings, design files, mechanical files for fabrication, firmware code, etc.). "Attribution" (6) is another addition that reflects important specificities in hardware distribution: this item calls for the attribution of the licensor in the distribution of a derived project or product, and suggest that trademarks in product names be altered (to preserve the business of an original contributor) but not enforced in a particular shape or form, such as requiring the inclusion

on a printed circuit board, to prevent creating an unreasonable and impractical requirement that may constitute a barrier for adoption.

The other items in the hardware definition follow closely the original software definition without introducing any novelty, except for the inclusion of the term "(11) hardware" to the already established moral and legal orientations of FOSS licences. One important absence, however, has to do with the lack of a clear orientation toward the openness of the hardware development "toolchain," that is, the collection of software tools that are necessary for opening, manipulating, compiling firmware code (or synthesising "gateware" for programmable logic devices) and fabricating hardware. The definition limits itself under the item "(1) documentation" to suggest that a "licence may require that the design files are provided in fully-documented, open format(s)."

The Open Source Hardware Definition has been influential in promoting collaborative development, but it does not properly account for specific technical challenges of drafting legal instruments to extend, and to an extent circumvent, conventional IP mechanisms. The requirement of the documentation to be publicly available is not the same in the two definitions, for example. The hardware definition specifies that the source must be made publicly available, but software one does not (in practice, since any recipient of software under an open source licence is empowered by that licence to make it public, this distinction is rarely significant). However, there remains room for legal and moral debates concerning the ability to keep the distribution private. This distinction is highlighted in the rationale behind the formulation of the patent provisions in GPL version 3, as well as the upcoming CERN OHL version 2, both of which allow modifications to the underlying design to be distributed privately (with any recipient being permitted to make the design public if they so wish).

The transposition of legal provisions from software to hardware is far from simple. Dispositions for FOSS licensing, either in permissive or reciprocal terms, cannot be assumed to hold for hardware as a utilitarian product. The FAQ of the "GNU General Public licence version 3" (GPLv3) elaborates on this problem in the clearest terms: "any material that can be copyrighted can be licensed under the GPL. GPLv3 can also be used to license materials covered by other copyright-like laws, such as semiconductor masks. So, as an example, you can release a drawing of a hardware design under the GPL. However, if someone used that information to create physical hardware, they would have no licence obligations when distributing or selling that device: it falls outside the scope of copyright and thus the GPL itself." (GNU GPL FAQ, source: https://www.gnu.org/licenses/gpl-faq.en.html, accessed 06/03/2018).

To address the challenge of establishing a solid legal framework for OH, the legal scholar John Ackermann, with the help of the FOSS expert Bruce Perens, drafted the first reciprocal licence, "Tucson Amateur Packet-Radio Open Hardware licence" (TAPR OHL) in 2007. Created in the context of the HAM radio community for helping hobbyists share hardware designs, TAPR was also introduced to create awareness with respect to the pitfalls of flexible, copyright-based open licensing, such as Creative Commons, for hardware projects. Two key definitions were introduced with this pioneer licensing effort: the definition of "documentation" which describes the set of design files, engineering drawings, and explanatory text, and that of "product" which refers to the fabricated hardware or parts of distribution kits. The reasoning behind this distinction is that the physical instantiation of a design is beyond the scope of copyright, except for a piece of hardware that embodies an artistic expression (Beldiman, 2018). One of the key contributions of TAPR was to include a provision for patent licensing, extending its role to a fundamental part of the "copyleft" mechanism in the licence by means of a fundamentally a binding contract in which licensor and licensee are granted patent immunity. For the open licensing provisions to be triggered, one must have "active participation in the life of the Documentation or Product" (Ackermann, 2009, p. 208).

TAPR also established reciprocal conditions with direct influence of the 4 freedoms encoded in the Free Software definition and transposed into a legal instrument embodied by the

GNU GPL. "This means," Ackermann affirms, "that the designer wants to ensure at a minimum that those who distribute the documentation for an Open Source Hardware project, and products based on that documentation, comply with two obligations: (1) that they make the documentation which they received under the Open Source Hardware licence available to all; and (2) that they likewise make their modifications to that documentation available to all on the same terms as the original work." (Ackermann, 2009, p. 193). Most importantly, the author calls attention to the fact that this aspect of OH can be defined as "irrational" from an economic standpoint, whereas we would suggest that it is better interpreted as a manifestation of ethical reasoning that is more suited to various forms of non-mercantile and academic exchange. When TAPR OHL was first released, it included one variant that was later discontinued, the "TAPR Non-commercial Hardware licence (NCL)" which was basically identical to the other licence, except for the non-commercial clause forbidding commercial exploration of OH designs (Ackermann, 2009, p. 205).

In 2011, the European Organization for Nuclear Research (CERN) released the first version of the CERN Open Hardware licence (CERN OHL) as a TAPR derivative. The CERN OHL was motivated by the need for a legal instrument that is tailored for CERN as a publicly funded, multi-lateral research organisation. Key concepts and provisions in TAPR were kept for CERN OHL, such as the notion of "documentation" to establish the scope of what is to be licensed; and, of great importance, the preservation of the copyleft mechanism inspired by the concept of Free Software (Ayass and Serrano, 2012). The third and last provision kept in the formulation of CERN OHL was the patent licensing clause. In collaboration with the IP expert Myriam Ayass from the Knowledge Transfer group at CERN, the OHL was designed primarily for transposing reciprocal provisions in the GNU GPL to the domain of hardware. In the words of Ayass's co-author, CERN engineer Javier Serrano: "we were trying to achieve much more than we had before: the ability for anybody who sees a physical object to trace back to the actual design file [...] We are trying to do reciprocal licensing which is much more powerful than just no-IP" (interview, 05/01/2017).

Another important OH licence was drafted by the legal scholar Eli Greenbaum with a focus on 3D printing: the "Three-Dimensional Printing Open licence" (TDPL). This reciprocal licence draws from other open licences, such a TAPR and CERN OHL, to stipulate provisions for the preservation of attribution and enforcement of access to 3D design documentation. In discussing its rationale, Greenbaum (2012) points out the need of clarifying legal issues concerning the possibility of sustaining hardware sharing with copyright and patent licensing mechanisms. The 3D printing case is of particular interest given its focus on 3D design, which implicate copyright infringement when they are copied (without authorisation) to the memory of a 3D printer and, then, transformed (sliced) for fabrication. It is this very possibility of triggering copyright restrictions through copying that Greenbaum utilises for establishing the TPDL reciprocal conditions. In principle, any object could be designed and fabricated, from flower pots to prosthetic devices, whereas copying (and converting) design files to the 3D printer is functionally necessary, generating a "one-to-one correspondence between the digital file and the object that is actually printed" (Greenbaum, 2012, p. 277) with notable differences with respect to the "resolution" which an object will be rendered by the printing equipment. This is not at all the case for other domains of hardware development, where different techniques as well as end results are involved, such as in "gateware" design with programmable logic devices (FPGAs) and application-specific integrated circuit (ASIC) technologies. This is yet another difficulty with respect to hardware: the very nature of the design, fabrication, testing, and distribution channels varies greatly, introducing serious roadblocks for creating a common framework for hardware sharing.

One of the latest efforts in OH licensing was the "Solderpad licence," drafted by an attorney with long experience in open licensing, Andrew Katz. In 2010, Katz released a document on a public mailing-list with "tracked changes" on the Apache licence version 2 to create a "permissive" alternative for hardware. His intention was to demonstrate that little modifications would, in fact, be necessary to create a new licence, filling an important gap where reciprocal licences existed, such as TAPR, CERN OHL, and TDPL. Solderpad

introduced a permissive option in the space of strong copyleft licences (Katz, 2012), allowing hardware licensors to extend the possibility of a particular hardware project to be converted into proprietary technology without the obligation of returning improvements and/or derivative versions to the electronic commons of Free and Open Source (software and hardware) projects. The mundane practice of copying or conveying a piece of software automatically constitutes copyright violation, whereas the same does not occur for hardware: "generally speaking," suggests Katz, "using a piece of hardware, or transferring a piece of hardware from one person to another does not potentially contravene any intellectual property rights, and therefore does not require any licence on which copyleft-type requirements can impinge." (Katz, 2012, p.45). Copyright does not cover utilitarian products, thus creating "a gap in the OSH licence enforceability (unless the contributor had separately secured patent protection)" (Beldiman, 2018, p. 42). Another important licensing issue has to do with what Katz (2012) called the "boundary problem:" questions often arise regarding the scope of FOSS licences when integrating different pieces of code with different licences, but it is much less clear for hardware the extent to which the integration of an OH hardware component, licensed with strong reciprocal terms, would make the whole hardware "copyleft." The modification of Apache 2.0 text in Solderpad was intended to address the smaller set subset of issues which are relevant in a simple permissive licence. It also included provisions for dealing with patents and trademarks (adopting the Apache 2.0 approach) that are particularly salient in the domain of hardware (Katz, 2012, p. 54).

3   Implications of open licence choice

Despite substantial advances in the preparation of OH licences in the past decade, there are issues still pending with respect to scope, enforcement, and liability. It is commonly suggested in expert debates that OH licences are difficult to enforce, given that it is difficult, if not impossible in many cases, to determine if a particular item of physical hardware was generated from design documentation under an open licence. One aspect of this critique refers to the lack of legal cases in which licences have been tested in court, as FOSS licences have (Beldiman, 2018). The scope of what is to be licensed is also questioned with respect to patent licensing. What patents of a licensor are to be licensed? To whom does patent immunity extend? Does it extend to licensees and/or users (or consumers) of OH products? These are salient aspects for comparing and contrasting existing alternatives.

Liability questions are often raised by companies willing to adopt OH development practices, but express a misunderstanding regarding how open licences guard against liability issues. In this respect, contractual questions concerning specific warranty and liability terms are transferred to the OH licensing debate, where they do not necessarily belong since open licences are supposed to be general-purpose legal instruments not case and technology specific. This is a controversial topic engaged by legal scholars and commentators of existing licences (Ackermann, 2009; Greenbaum, 2012; Katz, 2012; Beldiman, 2018). As in FOSS licensing, OH licences exempt licensors from liability by describing that the open design documentation is offered with no warranties and guarantees for any particular use or "fitness" for any kind of purpose. One important exception, however, is encoded in the TAPR OHL with an indemnification provision: "a hardware design publisher who receives no financial reward might reasonably request indemnification from someone who implements the design, distributes it to others, and thereby causes injury." (Ackermann, 2009, p. 209). The rationale for including this exception has to do with the possibility of harm induced by a particular OH product being fairly placed on the manufacturer (who receives payment) as opposed to the original designer (who does not). In other words, the cost of testing that the product is safe and fit for sale (and of appropriate insurance and, ultimately, the acceptance of liability) should lie with the manufacturer, and not the original designer.

It is useful to compare and contrast across licences with respect to their specific legal provisions. In the table below, we describe the 4 licences we discussed above with respect to their shared as well as contrasting provisions, identified by reference numbers.

Reciprocal terms, for instance, are enforced by most of the licences but not all of them (#1). Major differences can be interpreted by referring to the open licensing family from which a particular OH licence derived, that is, from permissive and academic licences to strong reciprocal ones (Rosen, 2004), but it is not sufficient to capture important distinctions.

The differences we describe reflect the purposes for which the OH licences were drafted. Despite sharing the concern for establishing a solid legal framework, important differences can be identified between them. The contexts in which TAPR and CERN OHL were drafted (respectively, the HAM radio community and the control engineering community in a multinational high energy physics laboratory) have one important parallel: both express the need for maintaining strong reciprocity ties between licensors and licensees (#1), while promoting wider circulation of projects (#2, #6, and #7). TDLP is motivated by the general economic benefits of hardware sharing in the domain of 3D printing, which is also one of the key motivations of Solderpad for creating a permissive OH licence. Whereas the former comes with reciprocal obligations, the latter drops it altogether, allowing for licensees to re-licence a project under a different licence (#3), thus granting the possibility for rendering it proprietary as well.

When considered as a set of constrains and freedoms licensees have with these four licences, there are specific injunctions that are particularly controversial. One of them consists in the demand for "contacting" the licensor with changes made to hardware documentation (#8). This requirement has been considered too demanding by many OH practitioners, therefore, the TAPR OHL author decided to redefine it in terms of a "best effort attempt" in contacting the licensor (if communication fails, no further action is needed according to the licence text). Similarly, the CERN OHL included in its first version this requirement, but later it was decided to make it optional.

Another important difference between licences concerns the specificities of their patent grants (#13, #14, and #15). One of the key issues that the TDPL was designed to address was the guarantee that downstream recipients have access to the proper documentation (#6) and attribution notices (#11) in the context of large-scale supply-chains for hardware manufacturing. The fundamental question here is how to ensure that an OH product will reach downstream users and producers alike with all the necessary legal provisions for keeping it effectively open for studying, modifying, redistributing, fabricating, and commercialising. While leveraging an open licensing framework for 3D designs, the TDPL also includes a patent licence of restricted scope: "the patent licence is tied to the copyleft obligations of the TDPL—only a licensee that is prepared to share derivative works in compliance with the obligations of the TDPL can enjoy the benefit of the patent licence" (Greenbaum, 2012, p. 291). Similar provisions are to be found in other OH licences, such as TAPR, CERN OHL, and Solderpad with the goal of deterring patent litigation, but TDPL presents a restrict version of this common clause.

	TAPR OHL (v.1.0)	CERN OHL (v.1.2)	TDPL (v. 1.2)	Solderpad (v. 2.0)
1. Allows proprietary derivatives	No	No	No	**Yes**
2. Allows unmodified redistribution	**Yes**	**Yes**	**Yes**	**Yes**
3. Allows redistribution under a different licence	No	No	No	**Yes**
4. Allows changing the text of the licence	No	No	No	**Yes**
5. Requires notifying changes	**Yes**	**Yes**	**Yes**	**Yes**
6. Requires providing the location for the documentation	**Yes**	**Yes**	**Yes**	**Yes**
7. Requires providing a copy of the licence	**Yes**	**Yes**	**Yes**	**Yes**
8. Requires contacting upstream licensor when distributing modified documentation	*Best effort attempt*	No	No	No
9. Requires contacting the upstream licensor when producing and distributing products	*Best effort attempt*	*Optional*	No	No
10. Requires including the old files with the new, modified files in the documentation	**Yes**	No	No	No
11. Requires copyright notice to be kept in documentation files	**Yes**	**Yes**	**Yes**	**Yes**
12. Requires copyright notice to be kept on products	**Yes**	**Yes**	**Yes**	No
13. Grants non-exclusive patent licence	**Yes**	**Yes**	**Yes**	**Yes**
14. Extends patent litigation immunity to owners of OH-based products	**Yes**	No	**Yes**	No
15. Includes patent retaliation clause in event of litigation	No	No	No	**Yes**
16. Includes grace period for bringing the infringing party into compliance	No	No	No	No
17. Grants trademark licence	No	No	No	No
18. Provides no warranty or guarantee of fitness for any use or purpose	**Yes**, but with one exception	**Yes**	**Yes**	**Yes**

Table 2: Comparison of OH licences.

Overall, key provisions in FOSS licences are replicated in the four examples we described above. The authorisation for using registered trademarks (trade names, marks, and product names, for instance) is not granted for commercial reasons by any of the aforementioned licences, which forces derivative projects to create their own identity and build their reputation (#17). Another important common clause concerns the limitation of liability (#18): OH is provided "as is" in all cases without any warranties or guarantees regarding its "fitness" for any purpose. Other important FOSS provisions are to be found such as the obligation for notifying changes (#5) and providing copyright notices (#11) to be kept on final products (in order to emphasise the derivative character of a particular project) with the exception of the non-copyleft case of Solderpad.

4   Conclusion

In this case study we examined OH licences primarily as instruments of coordination and collaboration for hardware development. We suggested that open licensing practices are better understood as means for achieving community goals: they encode moral and legal sensibilities that are shared by engineers and scientists to facilitate exchange with important socio-economic implications beyond expert techno-scientific domains. OH licences play, in sum, an important role in describing the conditions to enable fruitful collaborative dynamics. The extent to which OH licences can be used for enforcement of community goals, however, is still unclear and object of present legal and socio-economic scholarship.

For the purposes of policy-making, it is important to emphasise two emergent trends with broad implications: the first describes ongoing efforts to improve OH licences in terms of their accessibility, clarity, and scope. The second trend concerns the elaboration of industry standards (such as "DIN SPEC 3501" for standardising "best practices" for OH documentation) and establishing certification programmes, such as the "Open Source Hardware Certification" initiative of the Open Source Hardware Association (OSHWA). These trends contribute, at once, for the resolution of legal and commercial barriers for wider OH adoption (Bonvoisin and Mies, 2018).

To reduce complexity in the legal framework for OH licensing, more clarity and flexibility will be introduced with the forthcoming publication of the CERN OHL, version 2. This new licence will include a suite of sub-licences, from "strong reciprocal" (CERN-OHL-S), "lesser reciprocal" (CERN-OHL-L), to "permissive" (CERN-OHL-P), that encompasses all the alternatives we describe on Table 2. This licensing suite will also cover most use-cases across domains, offering extended compatibility with other licensing schemes for both software and hardware, akin to what Creative Commons accomplished for flexible copyright licensing of cultural and artistic goods.

In addition to flexible licensing options, the CERN OH version 2 will introduce two important concepts: the concept of "conveyance" or distribution of hardware sources as a means for reliably triggering the legal provisions of the licence (with direct inspiration from the definitions of GPL v3); and the concept of "available components" which creates an important space of exception in OH designs for parts that are widely available but are not "open" *per se* (such as resistors, capacitors, and other common components with well documented characteristics and interfaces). These concepts promise to solve ambiguities in the formulation of both TAPR and CERN OHL v1.2 (Greenbaum, 2012) while enabling an economy of hardware sharing in the context of proprietary development.

Commercial applications will benefit greatly from an improved legal framework, but also from further development of documentation standards and certification programmes for OH projects and products. Currently, little clarity and empirical research exists on the integration of proprietary hardware and legacy infrastructures with OH projects. It is otherwise well established in the academic literature and community debates that Free and Open Source development is not antithetical or detrimental to commercial applications (Balka, 2011; Petrinja, Sillitti and Succi, 2011; Höst and Oručević-Alagić, 2011; Shahrivar,

Hassanzadeh and Montazer, 2018). Serrano (2016) summarizes this debate in terms of a win-win situation: where commercial *and* free (in the sense of the freedoms any licensee can exert by drawing from open-licensed hardware) prevent, at once, the burden of non-commercial projects on original licensors and the risks of vendor lock-in of commercial hardware.

Open licensing can help us unlock the socio-economic potential of hardware sharing for public, educational, and private organizations, but institutional support is still needed for establishing sustainable structures. The "Global Open Science Hardware Roadmap" (Murillo, Molloy and Dosemagen, 2018) prepared by more than 100 authors (including hardware engineers, researchers, community members, and company owners) described public policy needs along three axes: "learn," with a focus on the investment in empirical research on hardware projects and commercial enterprises; "support," with a description of institutional and funding programmes; and "grow," with the goal of rendering OH more accessible by supporting wider distribution of projects and products. In terms of concrete public policy recommendations, it was suggested: 1) building a common pool of open data on OH projects to support the study of challenges and solutions across areas of application; 2) train technology transfer offices in open licensing frameworks; 3) further developing Free and Open Source tools to render hardware development more accessible and less dependent on proprietary toolchains; 4) preparing guidelines for testing, calibration and validation of OH vis-à-vis existing industry standards (Oberloier and and Pearce, 2017); and, lastly, 5) establishing public procurement policies that mandate the inclusion of OH (Serrano, 2016).

In addition to these policy recommendations, we suggest investing in commercial OH initiatives for emergent markets in educational and scientific fields (Pearce, 2017). With the combination of an improved OH licensing framework, documentation standards, and certification programmes, the OH community will have all the basic elements in place to unleash its promise of enabling a wide-ranging economy of hardware sharing. The role that the OH licensing framework plays in this context, as described in this paper, is fundamental: first, by creating an informed expert public around OH development with clear guidelines, standards, and commercial alternatives; and, second, by dispelling fear, uncertainty, and doubt about OH development methodologies more broadly. If these initiatives find support in "Open Science" policies, for example, OH will become one of the key approaches for the development of digital technologies in the public interest in the next decade.

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The present case study examines the implications of open hardware licensing through the analysis of the four most relevant licences in current use. The case describes the differences between open hardware and Free Open Source Software (FOSS) licensing to discuss the promises and challenges of creating and fostering a culture of hardware sharing. Open licences constitute primarily a *social contract* that describe conditions, obligations, and constraints for the public circulation of design documentation. Finally, the case discusses open issues in open licensing, broader implications, and offer policy recommendations for open hardware adoption.

Studies and reports