Breathe In, Breathe Out: How open hardware licensing can help save the world

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Abstract
As with any other open source field, there are countless far-reaching advantages in open hardware licensing, as opposed to its proprietary counterpart. This paper takes the example of a low-cost portable mechanical ventilator design and considers the effect of the application of the three different variants of the newly-released CERN Open Hardware Licence Version 2. This paper considers the importance of licensing, and demonstrates how open hardware licensing can facilitate efficient further development of a project, improve its safety and reliability, and encourage collaboration. Most importantly, open hardware licensing allows anyone to freely use, study, modify and distribute improvements to project design, and make, sell or otherwise distribute products made to that design, making it a cost-effective means of developing and deploying the device throughout the world, from the most developed to the most vulnerable territories. Finally, this paper argues that open hardware licensing also encourages economic activity whilst it protects third-party intellectual property rights.

Keywords
Open source; open hardware; licensing; CERN; ventilator; medical equipment; accessibility; CERN-OHL

Addressing a societal challenge

In 2010, a group of students from Massachusetts Institute of Technology and Boston University designed and prototyped a low-cost portable mechanical ventilator[1] that would help treat respiratory diseases, such as asthma or chronic obstructive pulmonary disease, in less developed countries. Although ventilators for artificial respiration have become commonplace in hospitals across many developed countries, they are provided at a cost of up to $30,000, with an equally high level of technological complexity. In their project, the students therefore set their sights on maintaining the

1 Abdul Mohsen Al Husseini, Heon Ju Lee, Justin Negrete, Stephen Powelson, Amelia Servi, Alexander Slocum, Jussi Saukkonen, *Design and Prototyping of a Low-cost Portable Mechanical Ventilator*, Proceedings of the 2010 Design of Medical Devices Conference (2010)

medical function of the ventilator, whilst reducing its price and making it easier to build. As a result, they developed a prototype whose bulk-manufacturing price was estimated to less than $200. Had the project been appropriately licensed and the ventilator began to be manufactured, it could have surpassed a great deal of similar projects[2] and helped doctors around the world saving lives of patients suffering from respiratory diseases, including from the recent outbreak of coronavirus disease COVID-19.

Although the students had planned to carry out further testing of their prototype and develop the idea so that it could be licensed for manufacturing,[3] they have only recently announced that they will make their material publicly available to help to find the solution to the global lack of ventilators in the COVID-19 pandemic.[4] Their announcement came only days after the initial submission of this paper. As more details about the project are being published day by dayand given the rapid pace of developments in the medical field these days, we have had to base our analysis on a number of assumptions made before the full disclosure of the project's details.

Given the project's praiseworthy aim to increase availability and affordability of medical equipment and its initial lack of appropriate licensing, we have analysed the project to discuss the most appropriate licensing strategy for its fast, effective and large-scale deployment. Also, as the students had published the project report in an academic journal, we assumed that they intended to make the prototype freely and publicly available, as opposed to keeping it a secret and proprietary. We have seen this as an opportunity to consider the project in light of available open source hardware licences, namely the recently published version 2 of CERN-OHL.[5]

Do you need a licence?

Attaching a licence to a project that is intended to be made publicly available, so that it can be freely studied, used or possibly improved by anyone, may sound counter-intuitive but, in fact, it is necessary.

The rules of copyright law[6] automatically apply to a new work without registration and use by third parties is not possible without a licence, Ifanyone wants to copy or modify the project documentation they would first need to obtain (in the absence of any copyright law exception) the students' permission to do so (assuming that they, and not their institution, were the copyright holder) . This may prove challenging in practice and would be given through the grant of a licence from the students.

. In some jurisdictions, including England and Wales, copyright laws could also prevent anyone without such permission from *creating a physical design* based on the project documentation.[7] Also, whilst the making and use of the ventilator based on the project may be allowed *for personal or non-commercial purposes* in some jurisdictions,[8] it may not be so in others.

Attaching a licence would therefore make clear to other designers and manufacturers if and to what extent they may study, improve, use and distribute the design, and manufacture and distribute

2 See https://www.instructables.com/id/The-Pandemic-Ventilator/ and https://medium.com/@RobertLeeRead/the-state-of-open-source-ventilator-projects-as-of-march-21st-1f36bfb608b4, both last accessed on 24 March 2020
3 See https://phys.org/news/2010-07-students-low-cost-portable-ventilator.html, last accessed on 24 March 2020
4 See https://e-vent.mit.edu/, last accessed on 31 March 2020
5 See https://ohwr.org/project/cernohl/wikis/Documents/CERN-OHL-version-2, last accessed on 30 March 2020
6 Other unregistered intellectual property rights such as unregistered design right, or database right, may also apply to aspects of the design materials, in various jurisdictions.
7 S. 213 and 226 of Copyright, Designs and Patents Act 1988
8 For example, see fair use provision of s. 107 of the United States Code. Likewise, Article 30(2) of Copyright Act of the Czech Republic stipulates that "copyright shall […] not be infringed by anybody who for his own personal use makes a fixation, reproduction or imitation of a work."

products made to it.

What licence should you use?

Considering the mechanical features of the ventilator project and its aim to improve access to medical equipment, an open hardware licence (OHL), such as CERN OHL, appears most appropriate.[9] As an open source licence, an OHL would permit anyone to use the design materials from the project to make a ventilator themselves, either according to the design, or with any changes they decide to make to it.

This would facilitate rapid adoption of the equipment and give other professionals an opportunity to review it. They could identify and correct any imperfections or create enhancements, making it safer and more efficient to use as a result.

Most importantly, attaching an OHL to the project presents a cost-effective way of making the ventilator affordable in developing countries where the cost of currently available ventilators presents one of the most significant hurdles in their use. Needless to say, the far-reaching societal benefits of open source have been acknowledged by many[10] and open source licensing has consistently been recommended.[11]

Why CERN-OHL?

The European Council for Nuclear Research (CERN) has recently published the second version of its OHL licence, CERN-OHL. As one of the most respected and widely used open hardware licences, and being associated particularly with electronic devices, itis an appropriate choice for consideration. CERN-OHL offers three variants to choose from: a strongly reciprocal variant (CERN-OHL-S),[12] a weakly reciprocal variant (CERN-OHL-W),[13] as well as a permissive one (CERN-OHL-P).[14]

CERN-OHL-S

As a strongly reciprocal licence, CERN-OHL-S requires that any derivative design based on an original design licensed under it, is also licensed under CERN-OHL-S should it (or a product made to it) be distributed, like copyleft. It also requires that the licensee makes available with their design all design documentation of the derivative design, including the necessary installation and interfacing information.[15]

The licence recognises that designs of many items, from mechanical devices to electronic devices, often consist of generally and readily available components ("Available Components").[16] Where this

9 See https://ohwr.org/project/cernohl/wikis/Documents/CERN-OHL-version-2, last accessed on 24 March 2020
10 See, for example, https://openuk.uk/, or https://www.gov.uk/guidance/be-open-and-use-open-source, both last accessed on 25 March 2020
11 The European Commission has recently opined that open source hardware could constitute a cornerstone of the future of Internet of Things (IoT) and the future of computing. See https://ec.europa.eu/digital-single-market/en/news/workshop-about-future-open-source-software-and-open-source-hardware, last accessed on 25 March 2020
12 See https://ohwr.org/project/cernohl/wikis/uploads/ee7922912e58f8676e1d7ff841b391cb/cern_ohl_s_v2.pdf, last accessed on 24 March 2020
13 See https://ohwr.org/project/cernohl/wikis/uploads/b94a1a92b29984226c56a0dd4dca0d39/cern_ohl_w_v2.pdf, last accessed on 24 March 2020
14 See https://ohwr.org/project/cernohl/wikis/uploads/055bd8b281d0805a3a38188838b370e1/cern_ohl_p_v2.pdf, last accessed on 24 March 2020
15 CERN-OHL-S, sections 1.3 and 1.8
16 Ibid, section 1.7

is the case, CERN-OHL-S does not (for physical components) require the licensee to provide exhaustive details of such components; it will suffice to provide enough detail so that they can be sourced and used to make the product or made themselves.[17] Of course, where a component is included that is not generally available, detailed information must still be provided.

Under CERN-OHL-S, the definition of Available Componentexempts the provision of interfacing and sourcing information and applies only to physical components. Therefore, if an original design is licensed under CERN-OHL-S then the licensor of a derivative design need not provide the full design documentation for any physical components available under a compatible licence, generally available physical components, or digital components available under a compatible licence.[18] Under CERN-OHL-S, readily available components which exist only in digital form, such as Hardware Description Language (HDL) cores, do not qualify as Available Components, so their Complete Source would have to be provided.[19]

Aside from being made of generally available physical components, such as a conventional bag-valve mask, cam arm, battery, motor and various tubes, the ventilator project also consists of an off-the-shelf Arduino Duemilanove microcontroller board[20] to control the functioning of the device.

The microcontroller on the Duemilanove (an ATmega 168 or ATMega 328) runs a simple piece of code: a logical loop where it responds to triggers ('*yes*' or '*no*') to prompt action and deliver intermittent breaths to the patient. While the Arduino Duemilanove itself qualifies as an Available Component of the overall design, how is our analysis affected when we take into consideration the code which runs in its microcontroller? Nothing changes. Code executed by a processor is not a component of that processor, the same way that the orange juice we use to fill a bottle is not a component of the bottle. The licensing regimes of the code and the hardware on which it runs are thus decoupled. Because the code is not a component of the hardware design, it is no necessary consider if it qualifies as an Available Component.

This leaves potential licensees with an important question: how can we make sure that code and hardware travel together, i.e that users always get a working ventilator? The answer is that licensing the hardware under CERN-OHL is not enough. There are two options. Either the licensor can also license the code explicitly under CERN-OHL (as a separate unit, or as a combined microcontroller+code unit), or (perhaps because the licensor is unable to make the code available under CERN-OHL, potentially because of licensing compatibility problems), they can apply another appropriate open source licence to the code.

If that code is a copyleft licence like GPL or LGPL, then on redistribution, the recipient is required to be given access to the source code under the same licence (it would, of course, be helpful if that source code were provided in, or through, a link available in the Source Location). In addition, the licensor would be well advised to give recipients additional comfort by seeking third party certification affirming that the project qualifies as open source hardware by complying with the OSHWA certification criteria, which stipulate that the hardware part of a project should be licensed under an Open Hardware licence and the software part should be licensed under a Free and Open Source Software licence.[21]

17 CERN, CERN OHL version 2 An Introduction and Explanation, available at https://ohwr.org/project/cernohl/wikis/uploads/0be6f561d2b4a686c5765c74be32daf9/CERN_OHL_rationale.pdf, last accessed on 24 March 2020

18 CERN-OHL-S, section 1.7

19 There is also an exception for components which are part of the normal distribution of a tool used to design or Make the Product. This acknowledges that many toolchains in the world of hardware are proprietary, and that they are likely to include items such as primitives, themselves proprietary, which will unavoidably end up in the design. This exception is mainly aimed at chip design, and this paper does not consider if further.

20 See https://www.arduino.cc/en/Main/arduinoBoardDuemilanove, last accessed on 24 March 2020

21 https://certification.oshwa.org/

Shouldn't we expect that software running on a board licensed under CERN-OHL-S be released under the CERN-OHL-S or another open source licence? No: and the reason for this is pragmatism. To explain, we provide an example.

It was recently revealed that many Intel x86 processors and their chipsets contain a microcontroller which runs a version of Andrew Tanenbaum's Minix operating system.[22] The Intel x86 processor chips themselves also run "microcode" which can be regarded as fundamental software which helps to execute the machine code instructions which the chips are designed to run. In each case, this is proprietary code. If there were a provision in CERN-OHL-S that *all* software and firmware running within the system must be open source, then this would prevent the use of almost any processor which uses microcode, including Intel x86 processors, and no doubt many other chips which also incorporate a small software stack. The reality is that these components are available to anyone, and users are provided with plenty of interfacing materials, so it would not be very useful to produce a hardware licence preventing a user from publishing designs using one of the most successful series of processors of all time. It would create even more serious problems, had a design for an Intel-based motherboard been made available under the CERN-OHL for several years, and become successful, before the discovery of the Minix stack in the Intel chipset had suddenly made the design retrospectively un-licensable.[23]

We already know that the Arduino Duemilanove qualifies as an Available Component under CERN-OHL-S, because anybody can buy one. For the sake of argument, let us see if it would qualify as an Available Component under another heading. Because the Arduino Duemilanove is itself open hardware, since the designs are freely available on the Arduino website, under a Creative Commons Attribution-ShareAlike (CC-BY-SA) licence, it might be considered that the Duemilanove is also available as Complete Source under a Compatible Licence. This is one of the ways a component can qualify as an Available Component under CERN-OHL-S (section 1.7(a)).

Unfortunately, this isn't the case, as CC-BY-SA is not compatible with CERN-OHL-S (or -W). Why? Because the CC-BY-SA requires that any changes to the design must, when distributed be released under CC-BY-SA (or a compatible licence[24]), and CERN-OHL-S requires that any changes to the design are, when distributed, released under CERN-OHL-S. Both of these requirements cannot be satisfied simultaneously.

Should Arduinos become distributed under CERN-OHL-S or -W (and we would ask that the rights holders of Arduino designs give serious consideration to dual-licensing them to enable this to happen), then the ventilator-custom Duemilanove would be capable of being regarded as an Available Component under section 1.7(a) ("licensed to You as Complete Source under a Compatible Licence").

CERN-OHL-W

CERN-OHL-W is similar to its strongly reciprocal counterpart, CERN-OHL-S, also requires that the licensee makes a great deal of information related to the derivative design available. However, it differs in its approach to virtual (including digital and software) components. While CERN-OHL-S

22 Steven J. Vaughan-Nichols, *MINIX: Intel's hidden in-chip operating system*, available at https://www.zdnet.com/article/minix-intels-hidden-in-chip-operating-system/, last accessed on 30 March 2020

23 A super-strong variant of the CERN-OHL which required that every piece of software and firmware within a design, including parts which were introduced by the tools, was suggested by people commenting on the licences during the drafting process, but it didn't seem that there were sufficient use-cases for this to be worthwhile. Maybe as hardware becomes more open in the future, this will be an option for a future licence.

24 CC-BY-SA 4.0 does contain a mechanism for allowing the out-licensing under a different compatible licence. The licences are selected through a process administered by Creative Commons. For example, it is possible to take a design licensed under CC-BY-SA and relicense it under GPLv3 (but not the other way around). It may be the case that CERN considers making an application to Creative Commons for one of both of the CERN-OHL reciprocal variants to be designated as compatible licences of CC-BY-SA 4.0.

only releases generally available *physical* components from strict information requirements, CERN-OHL-W extends this exemption to *any* component, including virtual ones.[25] As a result, where the derivative design incorporates a piece of code that is widely used and generally available (including under an open source software licence, for example), the licensee must acknowledge incorporation of such component in the project documentation, but need not include details about the making, testing, installation and interfacing of that code. This difference is most relevant in cases where the Open Hardware design in question is for an Application-Specific Integrated Circuit (ASIC) or a Field-Programmable Gate Array (FPGA). Since this article is about ventilators and similar hardware, we will not delve more into this side of things.

Another important difference between the -S and the -W variants is that a -W design can be merged into a larger design through a defined interface and the licensee doing this would not be expected to release the design details of the larger design. This is in contrast with the -S variant, whose strongly-reciprocal effect would result in an obligation to release the whole resulting merged design under CERN-OHL-S.

CERN-OHL-P

Finally, as expected, the "permissive" variant, CERN-OHL-P, permits the use, modification and redistribution of the design in any proprietary design. This may be particularly attractive to some businesses, as it allows them to develop the design and make products to it without having to release the design documentation. It's important to realise that designs licensed under any variant of CERN-OHL can be produced in a commercial context: none of the licences prevent commercialisation of the product, but the reciprocal variants do require the design documentation to be made available (and potentially used by competitors).

Allowing commercial use is justified

There are numerous alternative licences that may be considered for licensing the ventilator project, such as Creative Commons Non-Commercial licences (CC-NC). By explicitly excluding re-use scenarios leading to monetary compensation or other commercial advantage, these licences appear to serve public interest. However, this is not necessarily the case.

Licensing a project under a CC-NC licence only imposes non-commercial use on the subsequent use of the project by third parties, not its commercial exploitation by the original rights holder (assuming the original rights holder holds *all* the rights, and has not acquired some of the rights through the involvement of a community of contributors who have themselves contributed back to the project under a CC-NC licence).

As a result, the original licensor may effectively become the exclusive commercial user of the project and protect its commercial interests.. This may also negatively impact the ability of a community to coalesce around the project. It also creates the added complexity thatany improvements which are made to the design and which are re-submitted to the project under an NC licence, cannot be used by the original licensor (or anyone else) on a commercial basis.In addition, the terminology of CC-NC is subject to some dispute as to what constitutes a commercial advantage; this can range from profits to reputation, short-term to long-term.

In the current crisis,[26] it is important to maximise the production of high-quality ventilator designs as quickly as possible. To add a hurdle to commercial organisations – the very organisations with tooling and expertise to produce the ventilators –does not make sense, since there is no shortage of

25 CERN-OHL-W, section 1.7

26 Coronavirus disease (COVID-19) pandemic, see https://www.who.int/emergencies/diseases/novel-coronavirus-2019, last accessed on 30 March 2020

demand.

It's also important to note that in the world of software, the raw materials – zeroes and ones – are free of charge and in infinite supply. Hardware, by definition, requires atoms which (almost always) need to be purchased, and therefore, it is almost impossible for an open hardware project not to involve the injection of commerce at some point.

For these reasons it makes sense for a licence which permits commercial use to be relied on, but also one which encourages the sharing of designs and their improvements (including production engineering improvements, and market-specific improvements), and allows suitably equipped makers to collaborate with minimal friction to provide a suite of the best designs available for different markets, different applications, and different locations. Either the CERN-OHL-S or CERN-OHL-W would be ideal for this purpose.

Patents

The Creative Commons licences expressly exclude patent licensing, which means that a participant in the ventilator project which holds patents could simultaneously license the copyright in their designs in an open way, and at the same time withhold any patents necessary to produce and use those designs. This would seem unfair and unreasonable, and the CERN-OHL licence suite is intended to address this issue. It does so in the same way as many more modern open source software licences, by both providing an explicit patent licence covering contributions made to a project, and also with a patent retaliation clause which removes rights granted to a licensee should they start attacking a licensor for patent infringement in relation to the design.

Other features of the CERN-OHL-S and -W

A particularly attractive feature of the reciprocal versions of CERN-OHL is the requirement that a licensor may apply to ensure that details of a Source Location are provided on any Product made to the design, whether on the design itself (for example, a short-form URL placed onto an object as part of the 3D printing process, or silk-screened onto a circuit board), or on its packaging or documentation. This requirement may be particularly powerful if the Source Location details are placed onto the ventilator itself. If anyone can easily track down the design documentation, they can also use it to troubleshoot and fix any problems, even if they do not intend to replicate the entire device.

Conclusion

We recommend that any projects releasing open hardware designs for ventilators should give careful consideration to licensing them under CERN-OHL-S or CERN-OHL-W (either v2 or any later version). We also suggest that they consider licensing any necessary software or firmware under the same CERN-OHL licence, either separately, or as part of the whole design. If that is not possible, then we recommend consideration is given to an appropriate copyleft licence such as a version of the GPL or LGPL.

We contend that this enables commercial entities to collaborate easily to create the physical product, while at the same time allowing appropriate protection for patents, third parties and users. It also potentially means that, should the same reciprocal licence be employed, it becomes very easy to mix components between different designs where necessary, and also to potentially locate the relevant information necessary to maintain, fix and operate the devices in the field.

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