White Rabbit

Open Science Monitor Case Study

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Acknowledgements

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1 Introduction

The present case study analyses White Rabbit, an open source hardware developed at CERN, the European Organization for Nuclear Research, in collaboration with a wide range of organizations and companies. Open source hardware refers to hardware or tangible artifacts - machines, devices, or other physical things – "whose design is made publicly available in a way that anyone can study, modify, distribute, make and sell the design or hardware based on that design" (source: Open Source Hardware Association .)

White Rabbit is a new clock and event distribution system for the existing accelerator timing systems for CERN's particle accelerator (and de-accelerator) network. Beyond its deployment in numerous scientific infrastructures worldwide, White Rabbit has already shown its innovation potential by being commercialized and deployed in different industries, including Telecommunications, Financial Services, Smart Grids and Air Traffic Management. Currently, the technology is in its final stage for standardization and is estimated that by the end of this year (December 2018).

White Rabbit offers an example of how CERN managed to transform the open source software model to capital-intensive innovations; that is, motivating self-interested actors to freely reveal innovations developed with private resources without compensation guarantees. CERN developed White Rabbit as open source hardware with its primary adoption by other research infrastructures with similar challenges in network latency, and later, to diverse, industrial applications. The organization managed to openly share all the knowledge produced within the R&D process of White Rabbit with no IP or knowledge restrictions, yet was able to successfully transfer the technology to the market.

White Rabbit is considered today a flagship project at CERN infrastructure (Murillo and Kauttu, 2017). Its broader societal and economic relevance largely surpasses the specific scientific activity of large-scale facilities devoted to basic research such as CERN. Its importance concerns the practice of "experimental innovation" with unexpected impact on: education and training for different stakeholders involved in White Rabbit development; business opportunities for SMEs, which can rely on a distributed knowledge infrastructure to provide their services; the animation of broader internationalized science and engineering collaborations for maintaining and expanding research infrastructures; and finally a resource for validating scientific results (Murillo and Kauttu, 2017; Murillo, 2018).

The severe complexity and heterogeneity of the contributors to White Rabbit's development, combined with the plurality of market adoption trajectories, provides a unique opportunity to explore the phenomenon of open scientific hardware and its potential for the European economy.

2 Background

The development of research in particle physics is a cumulative process where the evolving theory informs the empirical experimentation, and, in turn, such experimentation refines the scope of theory development by supporting or refuting hypotheses. Since the 1970s, particle physicists have used the so-called Standard Model to describe the fundamental structure of matter. At CERN, the European Organization for Nuclear Research[1], researchers have used the world's most powerful particle accelerators and detectors to test the predictions and limits of the Standard Model.

The "Beams department"[2] is at the heart of CERN accelerator facilities and provides the technological instruments and infrastructure to its larger community. It is responsible for

[1] CERN website: https://home.cern/
[2] About Beams- CERN website: https://beams.web.cern.ch/

the design and R&D to meet the engineering challenges in the construction of the accelerator and detectors; the upgrading of the existing machines; the construction of key components to enhance extant capabilities; and new operational processes and experimental techniques that were not conceived when the infrastructure was designed. In sum, they are responsible for the development and operation of the entire technical infrastructure supporting CERN´s scientific work.

How does Beams engineers develop the technology to support the empirical experimentation? It all starts with the theoretical specifications that inform physical performance requirements required by scientists to run the experiments. As Autio et al. (2014) describe, this set of physical performance requirements leads to explorative R&D that helps translate such specifications into technological design choices for experimentation. CERN, either alone, or in collaboration with other scientific partners, identifies the most promising technologies to complete each task with corresponding specifications. Once the detailed technical specifications are defined, CERN launches a public call for tenders and selects the suppliers that can best provide the needed technologies at the best price, often initiating a collaborative R&D project for the design and manufacture of such technologies.

With the emergence of some success stories of open source hardware, such as Arduino, an open-source microcontroller board, and accesible digital fabrication technologies, engineers and scientists throughout the worldwide look for basic, customizable scientific hardware to carry their experiments (Pearce, 2012; Pearce, 2014; Baden, et al., 2015). Examples of open scientific hardware produced in other research fields include (Pearce, 2017): biotechnological and chemical labware (Lucking et al., 2014; Gross et al., 2014; Su et al., 2014), automated sensing arrays (Wittbrodt, et al. 2014), optics and optical system components (Zhang et al., 2013), DNA nanotechnology lab tools (Damase et al., 2015), magnetic resonance imaging systems (Hermann et al., 2014), and numerous others.

In 2008, Beams Department at CERN needed a technology capable of delivering unprecedentedly accurate time synchronization for their accelerators. They were trying to mitigate the problem of limited bandwidth and the impossibility of dynamically evaluating the delay induced by the data links that characterize CERN´s geographically distributed computing infrastructure. Engineers were looking for the evolution of the General Machine Timing (GMT) program, and formulated the following unprecedented specifications (Moreira et al., 2009):

- Transfer of a time reference from a central location to many destinations with an accuracy better than 1 nanosecond and a precision better than 50 picoseconds;
- Ability to service more than 1000 nodes;
- Ability to cover distances of the order of 10 km;
- Data transfer from a central controller to many nodes with a guaranteed upper bound in latency.

The project started with the collaboration of CERN and GSI Helmholtzzentrum für Schwerionenforschung[3], a large-scale accelerator facility in Germany. Two Spanish companies funded by the Spanish Ministry of Industry and Commerce joined later White Rabbit (WR) development to support WR software and hardware. In a next step, through a proactive engagement of CERN, a larger group of companies and organizations joined the development of hardware, software, and drivers for WR switches and nodes. While the first two companies engaged in the development were financially compensated for their work via the support of the Spanish government, others participated in exchange for the knowledge produced during the development process. Soon, WR ecosystem grew and include diverse organizations developing open hardware (n=4); proprietary hardware

[3] GSI website: https://www.gsi.de/en/researchaccelerators.htm

(n=6); software (n=1); firmware (n=1); and others developing long-distance WR applications (> 100 km) (n=1)[4].

Two years later, WR emerged as a switched Ethernet network in which nodes automatically receive sub-nanosecond synchronization. White Rabbit extends Precise Time Protocol (PTP) standardized as IEEE 1588, in a backwardly compatible way to achieve sub-nanosecond accuracy. WR switches allow users to establish highly deterministic data networks, due to having internal queues for Ethernet frames of diverse priorities, as set up by the priority header set in IEEE 802.1.Q.

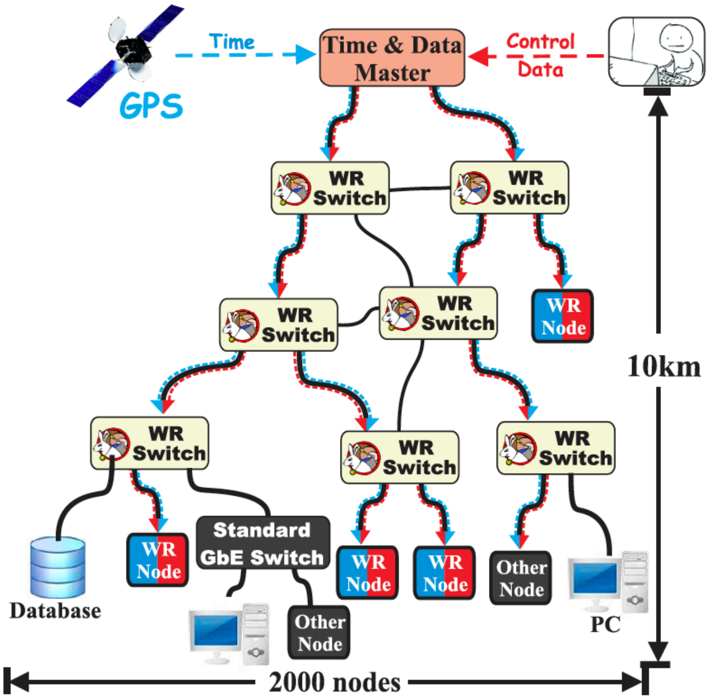

Figure 1. White Rabbit representation of switch synchronization hierarchy (Moreira et al., 2009)

At present, White Rabbit is considered a flagship project of Open Hardware (Murillo and Kauttu, 2017), due to its capacity "to bridge institutional spaces, disciplinary fields, and connect techno scientific experts through collaborative practices, shared tools, and protocols." (ibid., p. 27).

3 Drivers

The principle of openness is stated in CERN's founding convention, and the organization has been a relentless pioneer in this regard since the release of the World Wide Web under an open source model back in 1994. CERN has continuously embraced the principles of open science, such as open access with the Sponsoring Consortium for Open Access Publishing in Particle Physics - SCOAP3 and all LHC publications have been published under Open Access conditions; open data, setting up the Open Data Portal for the LHC experiments or Zenodo a free Open Data repository launched by the organization for use beyond the high-energy physics community; Invenio, an open source library management software package; and their use of open source licenses (Nilsen and Anelli, 2016; Murillo and Kauttu, 2018).

[4] Information according to the last update in White Rabbit repository: https://www.ohwr.org/

When CERN decided to develop WR as open source hardware to solve a problem in their accelerators, they had the intention to widely disseminate the technology to maximize its value for society.

Furthermore, open source products in software are recognized for offering decreased dependency on monopoly suppliers (Bruns, 2000; Kogut and Metiu 2001). This is analogous to hardware and it is especially valuable for scientists. By adopting a similar approach for WR development, CERN intended to develop a platform to integrate a variety of contributions from disperse stakeholders, while moving away from a vendor lock-in situation, where scientific infrastructures build dependencies with technology providers for highly specific technologies.

Such a framework provides the required flexibility, which is an important characteristic for scientists who need customized, never-before-seen equipment for their experimental endeavors in uncertain and modular environments.11 Such flexibility arguably leads to a better and faster progress of science (Pearce, 2014). By developing White Rabbit in the open, CERN was seeking to pave the way for the high customization potential of the technology, while fostering dynamic peer-review by a community of experts who can provide useful input, test cases, and feedback in an open space.

In addition, by adopting such an approach, CERN was also expanding the possibility of reusing the designs of other electronics engineers working in experimental physics laboratories. The idea was to increase the efficacy of the technology by reducing the number of different teams working independently on similar problems and focus disperse yet complementary knowledge on a central goal.

4 Barriers

While CERN sought to maximize their social and economic impact by widely and openly disseminating the technology, it also ran the risk of de-incentivizing companies to engage in the R&D of White Rabbit without legal mechanisms to ensure a fair economic return for their contributors.

The main challenge of open source scientific hardware is to capture rents from a collaborative R&D effort developed in the open. The difference between open source hardware and purely open source software are basically that, while marginal costs of software distribution are almost zero, in hardware there are the manufacturing costs of the physical artifact, which have an effect in the overall development and technology testing. In addition, while the investments in open source software are mostly made by users of that software (developers), in the case of hardware, the development requires both users (i.e the scientific infrastructures) as well as hardware manufacturers. A third important difference is that while in open source software participants join voluntarily, open scientific hardware often requires the proactive engagement and recruitment due to the magnitude and type (i.e not only time but production costs) of the R&D investment for critical technology projects such as White Rabbit. Consequently, there is a significant risk of not achieving the appropriate critical mass of the consortia to amortize R&D costs across a large enough group of stakeholders. Additionally, there is an overall negative perception of "Open Source Hardware" as hobbyist technologies without support (Serrano, 2016) and a debate about the potential (or inexistent) market for open science hardware (Murillo and Kauttu, 2017; Pearce, 2017).

So the question that emerges is: How did CERN manage to convince a group of organizations and companies to invest in the R&D of White Rabbit without protecting their assets from unfair appropriation?

CERN managed to purposefully engage different organizations by setting up incentives. CERN proactively stimulated both the supply and demand side of White Rabbit technology, nurturing the technological development while fostering the commercial uptake of White Rabbit in a set of diverse business applications.

In order to stimulate the **supply side**, CERN staff made substantial efforts to support, monitor, and train the suppliers. These efforts were not only focused on technology, but also in the first steps of market adoption of WR through the support of the Knowledge Transfer Office at CERN. In some cases, CERN themselves facilitated contact of White Rabbit suppliers to the first industrial customers. CERN did this not only to stimulate the commercial uptake but also to build additional supplier capacity in the ecosystem to guarantee some redundancy in their supplier network.

Another element motivating companies to join White Rabbit development were the expected knowledge and reputational benefits that companies could realize. Specifically, organizations were envisaging an upgrade of their technical skills by closely collaborating with highly qualified engineers at CERN and GSI. Additionally, organizations engaged in the development expected to be differentiated from future market competitors by being considered a tier-1 partner of CERN and GSI. The branding and reputation of such collaboration were expected to signal the quality of the organization while extending the companies' capacity to attract clients.

Furthermore, in order to transform White Rabbit into a large community, CERN not only had to proactively engage new companies capable of providing White Rabbit technology, but also it had to govern the exchanges, being an arbiter of differences when needed (Serrano, 2016). The different organizations involved in WR development accepted the arbitrage of CERN in the different exchanges and its leadership.

A legal framework was also provided by CERN to foster the knowledge sharing among the diverse organizations. The CERN Knowledge Transfer Group along with its engineers developed the CERN Open hardware license (CERN OHL), which first version was released on March 2011.

CERN found inspiration in the "Tucson Amateur Packet Radio" license (TAPR[5]). TAPR, a non-profit founded in 1982, was born to support R&D efforts in the area of amateur digital communications trying to support affordable and useful kits for electronics hobbyists. In 2005, the organization was asked for support by a group developing high-performance software defined radio products, who feared that their efforts might be co-opted by commercial organizations (Ackermann 2009). Consequently, the TAPR Open Hardware License was created as one of the first hardware-specific open source license.

When CERN first released its Open Hardware license, it faced criticism by the existing Open Source Hardware community. As a consequence, CERN OH license authors launched a collaborative online project to gather feedback from the community and produce a refined version (version 1.2) of the license. The second adaptation looked lighter for the users because licensees under this version were not obliged to notify the changes to upstream licensors in this revised version. In addition, the new version included the notion of Documentation Location, in order to help recipients of the license obtain access to the design documents of a specific piece of hardware. Finally, the new version states that intergovernmental organizations like CERN are not singled out regarding their rights anymore, which means that CERN is no longer liable to other licensors or licensees.

Diverse collaborative practices, tools, and protocols were also put in place to facilitate stakeholder engagement (Serrano, 2016; Murillo and Kauttu 2017). Some examples include the Open Hardware Repository[6] created in 2009, a wiki and a dynamic mailing list. The Repository hosts more than 270 projects and 1200 units produced for more than 200 members according to the last numbers of Open Hardware Repository. The repository also contains a manifesto, which describes the rules governing the exchanges between stakeholders. Complementary to the online collaboration, a set of face-to-face meetings and workshops have been organized since 2008 until the present in different European

[5] Description of TAPR in Open Hardware Repository: https://www.oshwa.org/research/brief-history-of-open-source-hardware-organizations-and-definitions/

[6] Open Hardware Repository: https://www.ohwr.org/

premises, which include GSI (Germany), CDTI (Spain), Nikhef (Netherlands) or Barcelona in the framework of ICALEPCS conference in 2017. CERN itself served as a hosting institution for regular community meetings, which were composed of hardware engineers, software developers, scientists, and Open Science researchers, including the international "Gathering for Open Science Hardware"[7].

In order to convince suppliers to join the development of White Rabbit, openly disclosing the results of their R&D investments, CERN had to convince suppliers that there would be substantial demand for White Rabbit. The organization needed to boost the dissemination of White Rabbit potential markets. As a result, in order to stimulate the **demand side**, the White Rabbit community decided to formulate standards around the technology, which broadened White Rabbit awareness across industries. Going through a standardization process was envisaged to additionally increase the stability, viability, and credibility of the technology by soliciting the feedback of experts to further fine-tune the technology.

Different paths for White Rabbit standardization were assessed, which included the standardization at the International Telecommunications Union - Telecommunication Standardization Sector (ITU-T); the standardization at the Institute of Electrical and Electronics Engineers (IEEE) including White Rabbit into version 3 of the "Precision Time Protocol" (PTP); or standardization in other standardization bodies or consortiums. This process was implemented by the P1588 working group, which started in mid-2013. The group is composed by an estimation of 180 members representing different industry and scientific organizations around the world. At present, the standardization process is scheduled to complete by the end of 2018, with the publication of the final standard in 2019. Once the standardization process is finished, White Rabbit will be under the name of High Accuracy, the third default PTP Profile included in Annex J of the IEEE1588.

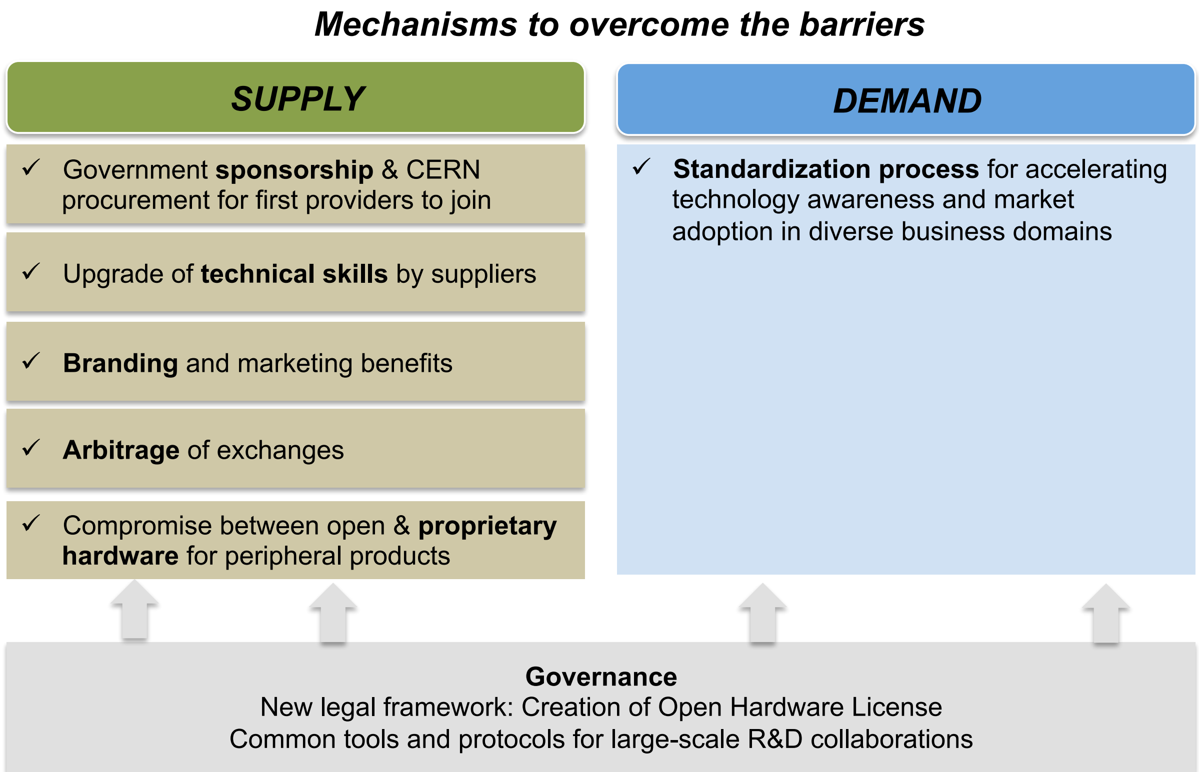

Figure 2. Summary of mechanisms to overcome the barriers

[7] GOSH conference website: http://openhardware.science/

5 Impact

5.1 For Science

As soon as a first version of the White Rabbit designs was published and commercially supported hardware became available, other scientific infrastructures and facilities started expressing interest in it. The scientific industry was the first to implement WR technology, which is a sizeable market in their own.

At present according to last updated in the WR repository, 30 organizations have implemented WR and 15 others are current evaluating if the technology can fit their purposes. The geographic scope of those organizations include: China (n=2); Czech Republic (n=1); Egypt (n=1); Finland (n=2); France (n=5); Germany (n=3); Hungary (n=1); India (n=1); Italy (n=3); Japan (n=2); Russia (n=2); Slovenia (n=1); South Africa (n=1); Spain (n=1); Sweden (n=2); Switzerland (n=2); The Netherlands (n=4); United Kingdom (n=4); United States (n=4); and international coalitions (n=3).

Besides those organizations, 9 R&D projects have applied White Rabbit technology for their scientific purposes. Some examples include DEMETRA - a partnership including scientific institutions, GNSS Industries and service providers that seeks to develop a prototype of a European time disseminator based on EGNSS- and tested for distribution Galileo precise UTC using ground fiber service .; EMC2 , an ARTEMIS Joint Undertaking project in the Innovation Pilot Programme 'Computing platforms for embedded systems' (AIPP5); Asterics , the astronomy ESFRI and Research Infrastructure Cluster, a project funded under Horizon 2020 framework by the European Commission; the European metrology programme for Innovation and Research (EMPIR); the EMRP - European Association of National Metrology Institutes - which is a jointly funded by countries within EURAMET and the European Union ; the joint research project NEAT-FT funded by European Commission, which aimed to investigate new techniques for phase-coherent comparison of remotely located optical clocks, separated by distances of up to 1500 km and focused on long distance testing of WR equipment (a test link of about 1000 km distance between MIKES sites at Espoo and Kajaani was set-up); Eureka Project 7634 Run Rabbit ; or WorldTiming (Ultra accurate world timing services) which is a European project funded under the SME instrument grant, that aimed at distributing ultra-accurate and traceable timing through optical fibers; amongst a plurality of other R&D initiatives that are constantly being reported an updated in White Rabbit wiki ..

Examples of this scientific application include GSI where WR became the timing system of the Facility for Antiproton and Ion Research (FAIR), an international accelerator based in Germany of an estimated investment of $2 billion, which uses antiprotons and ions to perform research in nuclear, hadron and particle physics, atomic, anti-matter physics, high density plasma physics, and applications in condensed matter physics, biology and the biomedical sciences. Also, the Cubic Kilometer Neutrino Telescope (KM3Net), a European research infrastructure located at the bottom of the Mediterranean Sea, uses WR in order to synchronize the detector units. It consists in a water Cherenkov detector with an instrumented volume of five cubic kilometers distributed over Toulon (France), Sicily (Italy) and Peloponnese (Greece).

5.2 For Industry

In addition to the first applications in the research industry environment, WR has moved one step further in its adoption and has already been commercialized and applied in very different settings, which include the application in Telecommunications, Financial services, Smart Grids, Air Traffic Management and Industry 4.0 applications.

Some examples of industrial applications include Vodafone, which implemented a WR proof of concept in Vodafone Netherlands network in 2017 with the collaboration of spin-off OPNT and Tallgrass, a company expert in fiber optic networks. Time was delivered with an astonishing small error of less than 1 nanosecond over a cascade of four sites, spanning a total distance of 320km. It was considered the world's first successful deployment of WR in the production network of a commercial operator to this date.

Another business application of WR was in financial services. Understanding order-of-trade execution is important for High-Frequency Trading (HFT) matching engines based on sequence. The recent financial regulation seeks to strengthen investor protection and foster transparency of financial markets (i.e new Directive on Markets in Financial Instruments – MiFID II adopted in June 2014 by European Parliament). One of the largest regional securities exchanges in Germany, the Frankfurt Stock Exchange, has adopted WR. Accuracy in financial services is required in the millisecond range, but WR allows high accuracy in the nanosecond range, allowing legal timestamping applications (Widomski et al., 2018).

Smart Grid is also an example of the business application of WR. The technology was tested in the field of smart electrical grids in the Milan financial district. Power distribution measuring devices depend upon reliable synchronization to be distributed across geographic areas, especially for Phasor Measurements Units and Wide Area Measurements Systems, which need accuracy in the microsecond range.

Air Traffic Control, like other critical safety applications, need accurate synchronization, this is the reason why WR attracted the attention in this sector. Modern Central Navigation Systems need synchronization accuracy. As an example, for an airplane flying at about 1000km/h, the error of synchronization of a single second defines an error position of 300 meters (Widomski et al., 2018).

Finally, regarding WR impact in industry, there is a potential market in any business setting where time accuracy is responsible for system failures that can cost considerable amounts of money or lives. At present, since WR has been in the process of standardization under IEEE 1588 working group P1588, which has 180 members from a wide range of industries, several business applications are emerging in diverse fields. The working group has effectively helped to increase awareness of the technology and different companies are currently exploring the possible implementation of WR, which include the field of industry 4.0 where there is a massive trend of increasing automation and efficiency in manufacturing that needs connected sensors and machines, autonomous robots and big data technology.

5.3 For Society

White Rabbit has achieved a relevant impact in society if we consider that more than 30 research infrastructures and scientific projects that have already implemented White Rabbit receive substantial public funding from national funding, or a combination of national and EU funding. The extra effort that CERN had to exert in order to orchestrate the collaborative development of WR is likely inferior to the savings that all those research infrastructures have realized when considering the alternative scenario of each one investing in their own solution.

A key issue for centres such as CERN or GSI is to assess their return on investment (ROI) and their benefits to the economy and society at large while sharing and widely disseminating their knowledge to boost new discoveries and enhance the efficiency and quality of research. WR is one of those examples were both organizations managed to optimize their resources and they successfully come up with a technology which has been extensively re-used in diverse industry fields showing, without a doubt, its innovational impact.

Finally, WR has been considered a flagship example in technology transfer also due to the diffusion of CERN open hardware license, which has been widely adopted by industrial and educational projects outside scientific fields (Murillo, 2018). Open Hardware efforts at CERN have served to support other free software/ hardware development experiences that benefit professional, scientific and educational sectors indirectly, allowing for increased public participation and accountability in IT development.

6 Lessons Learnt

Open scientific hardware is an emerging formula being explored by research infrastructures that produce experimental technologies. The example of WR provides relevant insights on how it is possible to go one step further from the model of open source software to other, more capital-intensive technologies that require different incentives, dynamics, and conditions, combining open revelation and technology commercialization. The open source approach possesses an "essential tension" about appropriating the returns from an innovation versus gaining adoption of that innovation (West, 2003). When moving away from a pure software technology, it can challenge the future commercialization of such technology by companies participating and co-investing in the development, which will be unable to appropriate the returns of such results. WR successfully managed this tension and can inspire other research infrastructures facing similar challenges.

We observed that White Rabbit would not even "take off" unless the right incentives were in place so that suppliers and other stakeholders would contribute their knowledge to an open source scheme where both R&D processes and outcomes were open to everybody. While companies increasingly seek to cooperate with other organizations outside firm boundaries to tap into ideas for new products and services (e.g Chesbrough, 2003), mechanisms that motivate innovators to openly reveal the processes and the outcome of their investments are not evident.

With White Rabbit, CERN managed to transfer the experiences of open source software and hardware development (e.g Pearce, 2017) in a complex, sophisticated and uncertain scientific setting. In addition to the diverse ingredients, there is a last and difficult explanation for this success story: The successful adoption of White Rabbit happened simply because it is a very good technology that successfully fulfils a clear need in a broad range of scientific and industrial settings.

7 Policy conclusions

Several policy conclusions arise from the White Rabbit case that are aligned with the philosophies of the Open Science community:

Including Open science hardware in public procurement when appropriate

Open Science Hardware community is increasingly asking for public institutions to require that the design of the hardware that they purchase should be published as Open Science hardware (Serrano, 2016; Global Open Science Hardware Roadmap.) We are already seeing similar experiences with free open source software, where there is a growing number of public institutions specifying in their call for tenders that software purchased through their public budgets should be open source. This reflects a desire of public organizations to maximize the positive impact of their spending. In scientific settings, a similar decision minimizes parallel and redundant investments by research infrastructures and incentivizes wider diffusion and adoption. However, the different consequences of such a decision should be further analysed and assessed by public funders and institutions.

Supporting Open science hardware through Technology Transfer Offices

As shown in the case of White Rabbit, there are several barriers that must be overcome and, in some cases, need institutional support from research infrastructures. Technology Transfer Offices can play an important role in order to provide appropriate support for open science hardware exploitation and commercialization.

Increasing awareness about Open Hardware licenses and agreements

Providing the appropriate legal framework, the case of White Rabbit facilitated not only the governance of the technology development in the open but was a key component for engaging companies and new players to the ecosystem. At present, there are different

Open Hardware licenses and agreements that already exists, in addition to CERN OHL, which include: TAPR OHL, Solderpad license, and the Open Material Transfer Agreement. Supporting the awareness and adoption of such licenses and the experience of research infrastructures and other players implementing them might help increase other potential open science hardware experiences.

Need for evaluation and monitoring

The further evaluation of other open science hardware cases and the identification of global trends and patterns are key to assess which policy levers lead to greater accessibility and success of hardware for science. Public research infrastructures need evidence of the effectiveness of open science hardware projects to make them accountable to funders, community supporters, and developers. They need also an assessment of how other experiences have succeeded in order to guide their actions when publishing a call for tenders, writing specifications, implementing an open science hardware project, and evaluating its impact. An analytical framework that assesses the economic, legal, social and cultural aspects of Open science hardware adoption across contexts can support public research infrastructures, policy-makers, funders, community supporters and developers in the implementation of open science hardware initiatives.

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White Rabbit is an open source scientific hardware developed at CERN in collaboration with a wide range of organizations worldwide and companies. Beyond its deployment in numerous scientific infrastructures worldwide, White Rabbit has already shown its innovation potential by being commercialized and deployed in different industries. White Rabbit offers an example of how CERN managed to transform the open source software model to capital-intensive innovations; that is, motivating self-interested actors to freely reveal innovations developed with private resources without compensation guarantees. The severe complexity and heterogeneity of the contributors to White Rabbit's development, combined with the plurality of market adoption trajectories, provides a unique opportunity to explore the phenomenon of open scientific hardware and its potential for the European economy.

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