Open Hardware as an Experimental Innovation Platform: Preliminary Research Findings

ABSTRACT

In this article we explore the notion of Open Hardware (OH) as an “experimental innovation platform” to take a first step in the study of its institutional and sociotechnical conditions. The primary data we use was gathered by the CERN Knowledge Transfer group in October 2016 through an online survey in addition to face-to-face interviews. Our preliminary findings point to the need of establishing different sources and modes of institutional support (beyond CERN and outside the hobbyist market), while helping to advance on-going initiatives to create physical and virtual collaboration spaces, examining the existent legal frameworks and their limitations, and secure investment for software development of design tools.

Keywords: open hardware; experimental innovation platform; dissemination; impact

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INTRODUCTION

Innovation studies have been transformed in the past three decades with the identification of the key role played by users in advancing the state-of-the-art in many professional and scientific fields (von Hippel 1988, 2004; Hyysalo, Jensen and Oudshoorn 2016). Questions of openness have been equally important in the study of innovation across distributed professional networks (Chesbrough 2003; Chesbrough et al. 2014) and organised publics for Internet commons-based peer-production (Benkler 2006; Kelty 2008; Fish et al. 2010). In this fairly recent but expanding research domain, Open Hardware (OH) constitutes an important object of inquiry for displaying new intra- and inter-organisational dynamics with much a higher degree of openness to public and private participation. Its contemporary relevance lies not only in promoting user-led invention but also in creating sociotechnical conditions for process innovation, drawing from both established and emergent institutional ecologies which are animated by experts and hobbyists, academics and non-academics, for-profit and non-profit enterprises.

In this article we explore the notion of OH as an "experimental innovation platform" to take a first step in the study of institutional and sociotechnical conditions for fostering and advancing OH projects at the European Organization for Nuclear Research (CERN). For our purposes, OH will be described as a key platform of a broader "knowledge infrastructure" which is comprised of "robust networks of [scientists], artefacts, and institutions that generate, share, and maintain specific knowledge" (Edwards 2014: 17). As integral part of the contemporary movement for "Open Science" (Fecher and Friesike 2014; Albagli, Maciel and Abdo 2015), OH will be examined with respect to its actual and potential contributions to the development of common tools and infrastructures for large-scale scientific collaborations. Creating and sustaining an experimental innovation platform means to cope with unprecedented sociotechnical uncertainty while also being truly accessible to emergent forms of public participation.

First, we will describe how OH is conceived as one of the mechanisms for knowledge transfer at CERN. Then, we will describe how OH serves as a platform in the broader context of collaborative research and innovation. Based on a preliminary survey with key actors at CERN and OH companies and community members, we will outline the contours of a collaborative innovation platform. Our primary quantitative and qualitative data were gathered by the CERN "Knowledge Transfer group" (CERN-KT) in October 2016. It contains responses from community members, engineers, hobbyists, company executives as well as CERN engineers, managers, procurement officers, and legal experts. The preliminary study we describe here was conceived by the CERN-KT group as a first step to establish a more robust empirical foundation for future OH initiatives at the interface between large-scale scientific organisations and "innovation communities," conceived here particularly as "nodes consisting of individuals or firms interconnected by information transfer links which may involve face-to-face, electronic, and other communication" (Hippel 2004: 96).

OPEN HARDWARE AT CERN

The CERN-KT group is tasked with the mission of disseminating CERN's technoscientific knowledge. OH is one of the novel platforms the KT group has embraced to accomplish its goals. In addition to design and collaborative hardware development with commercial partners, CERN-KT has broadened its support for new initiatives with supporting the creation of an innovation laboratory (IdeaSquare), various Open Access projects (such as "SCOAP3" and "CERN Document Server"), Open Data initiatives (with the long-term data preservation repository "Zenodo"), and Free and Open Source software projects, such as Geant4 (simulation software), INVENIO (for managing CERN's library), INDICO (for organising events), and ROOT (a framework for storing and analysing big data), among several others.

Introduced in 2009, OH was embraced as a knowledge transfer mechanism at CERN through the creation of the "Open Hardware Repository" (OHR). Created to facilitate exchange among hardware designers at experimental physics facilities, the OHR currently hosts more than 100 projects and more than 1200 units have been produced for over 100 end-users (Nilsen and Anelli 2016). In our estimates, the lead expert user and designer community around CERN OH projects consists of a little over 200 members with varying degrees of involvement. In comparison with the broader FOSS community, the CERN OH community is relatively small. Most of the design is done at CERN and by working closely with corporate partners and consultants. The current OH procurement volume is estimated to be in the order of half million Euros per year, and seventeen partner companies are currently working with the CERN OHR.

Before creating an OH license at CERN, the existent legal Open Source frameworks were examined, a public, online channel was created to consult with the community, and existent licenses were studied, such as "Tucson Amateur Packet Radio" (TAPR) which subsequently became the basis for the "CERN Open Hardware License" (CERN OHL) published in 2011 (Ayass and Serrano 2012; Powell 2012; 2016). The OHL was composed in collaboration between CERN engineer Javier Serrano and the legal expert Myriam Ayass to give OH licensees the right to freely study, extend, and commercially exploit electronic designs under the condition that new derivative work be distributed under the same licensing terms, basically transposing the key reciprocal obligation of the General Public License (GPL) to the domain of hardware documentation.

One of the most successful OH projects at CERN is "White Rabbit," an Ethernet-based network protocol developed for timing and data synchronisation with sub-nanosecond accuracy (van der Bij et al. 2013). White Rabbit has been identified as a flagship OH project at CERN for speeding up development and increasing knowledge transfer across academic, commercial, and public sector partners. This project is at the origin of the CERN OH initiative in 2006. At the time, Javier Serrano was appointed to facilitate the work of two teams for the LHC control infrastructure at the "hardware and timing" section (CERN BE-CO-HT), respectively the hardware design (responsible for custom electronics modules) and the software development teams (writing low-level Linux device drivers for their customised hardware). In this early experience, Serrano realised the need for building a similar collaborative space and culture for hardware development his colleagues benefited from in the context of the Linux project.

OH is one of many existent platforms in operation from within and across the HEP knowledge infrastructure (see Boisot et al. 2011 for the example of ATLAS at CERN). In its experimental quality, OH has the capacity to bridge institutional spaces, disciplinary fields, and connect technoscientific experts through collaborative ties. Its capacity to be adopted and adapted across expert domains is well know: many OH initiatives within and beyond the sciences have been directly or indirectly inspired by FOSS development models, tools, and values (Ackerman 2009; Serrano 2016). In parallel with FOSS, OH encompass a wide range of moral, legal, technical and economic forms, which carry the potential for alternative productive arrangements, as well as hard barriers of field expertise for increased public participation. Many projects have been build on OH as a platform, such as the Arduino and Lilypad projects for interactive design (Buechley and Hill 2010; Baker 2014; Faugel and Bobkov 2013; Flores et al. 2013), the RepRap 3D printing community (Soderberg 2010; 2013); the Luminex platform for determining cytokine protein content (Datta and Opp 2008) and the Berkeley Mote sensor project for civil infrastructure (Ruiz-Sandoval et al. 2006), among several other cases.

Overall, the benefits of creating, fostering, and expanding OH projects and products have been reported to increase the potential of knowledge transfer, increasing collaboration and speeding up troubleshooting due to frequent peer-review. Despite positive experiences reported by OH designers and users, the "coopetitive" dynamics across highly heterogeneous domains of commercial and non-commercial activity remain understudied and unknown to a large extend. In order to help advance OH research, we elaborated the following research question: *What are the conditions for creating, maintaining, and scaling an OH platform for the sciences?* Based on our preliminary research results, we anticipate some of the contours of basic sociotechnical conditions for creating a sustainable platform, which we will discuss in the following sections.

CERN OPEN HARDWARE SURVEY

One of the primary motivations for the "Impact of CERN Open Hardware study" was the need for understanding the collaborative and commercial dynamics of OH. In total, 149 cases were collected with an online survey and, after data clean-up of replicates and empty responses, the final dataset contained 146 responses from CERN OH participants (including legal and tech transfer experts, non-tech users and procurement officers) and the OSHWA mailing-list members (which has currently 396 subscribed members). The survey had questions on 1) basic demographics (including age group, education, area of work, self-identified roles in the community); 2) perceptions of key OH issues; and 3) more general aspects of coordination and participation (such as how participants would improve collaborations and how they monitor projects). For data analysis, basic descriptive statistics were computed, graphed, and tabulated (Table 1 and Figure 1). Questions of evaluation and perception were not quantified but visualised using a Lickert scale (Figure 2).

In addition to the survey, 14 face-to-face interviews were conducted with OH experts in Germany, Switzerland, The United Kingdom, Spain and Poland and two over the Internet when the interviewees were overseas. These interviews were collected with experts, users and more peripheral institutional actors within and outside CERN. The interview protocol included questions of participation, perception of benefits and challenges, IP licensing, and business models. The interview material was first transcribed and then analysed to identify overarching themes. The qualitative analysis was conducted by comparing and contrasting codes and annotations to elucidate what each interpreter found in the qualitative *corpus.* For the analysis we present in the next section, a final pass on the qualitative material was performed to refine the list of key-terms we generated. A matrix of "theme co-occurrence" was used to facilitate the analysis.

There are important caveats with respect to the scope of the "Impact of CERN Open Hardware study." First, the survey was meant as an exploratory device of limited depth and breadth, which is not to be taken as representative of the broader OH community. Since the goal was to learn about the basic profile, field expertise, and practical experiences of OH community members and businesses around CERN, the target groups were categorised according to their self-declared role as "supporters" (who are active members and vocal promoters), "procurement" (who are responsible for buying OH solutions within traditional institutional settings), "legal & administrative personnel" (who are responsible for making decisions on questions of institutional support), and "firms" (which are primarily dedicated to OH design and fabrication services). Key CERN OH supporters at were interviewed first and several contacts were snowballed based on their suggestions. Interviewees were also identified through the OSHWA mailing list after the survey at CERN was exhausted.

FINDINGS FROM THE EXPLORATORY SURVEY

In terms of the respondents' basic profile, most participants are young professionals (in their 30's and 40's), male-identified with post-graduate degrees. The majority has technical backgrounds, followed by scientific and management training. Occupations range from company employee to academic researcher, and a less than 20% of the respondents occupy top management positions. Interestingly, respondents are divided in two major groups of professionals in non-profit (55%) and for-profit sectors (45%). Younger age and gender disparity represent patterns which have been observed in many surveys conducted with members of the Open Source Hardware (OSHW) and Free and Open Source software (FOSS) communities (OSHWA Surveys 2012 and 2013). There is a concentration of respondents in their 20's, 30's, and 40's and the well known abyss between a majority of men *vis-à-vis* women-identified and other gender minorities in FOSS is represented here as well (Nafus, Leach and Krieger 2006; Reagle 2012). Location information was obtained through respondents'' affiliation information. Level of education represents yet another parallel with previous OSHWA and FOSS surveys: most respondents have academic education, but the biggest number has post-graduate-level education (master's and PhD's).

Age	**%**
18 – 24	3
25 – 34	39
35 – 44	35
45 – 54	17
55 – 64	5
65 or older	1
Location	**%**
Europe	49
North America	12
Latin America	7
Asia	4
Africa	1
Not-Available	27
Education	**%**
Ph.D.	31
Masters	40
Bachelors	21
Other	8
Gender	**%**
Men	89
Women	8
Other gender identifications	3
Job Title	%
Employee	29
Scholar	21
Entrepreneur	20
Manager	12
C Level Executive	10
Director, Vice-President	8
Job Function	**%**
Technical	59
Academic	19
Management	15
Administrative	5
Marketing	1
Sector	**%**
Non-profit	55
For-profit	45

Table 1: Respondents' basic profiles

In terms of reported roles in the OH community, most respondents self-identified as technologists (engineers and programmers) with popular identities, such as "maker", "entrepreneur", "hacker" as well as established ones, such as "researcher" and "designer." The second half of the respondents identified mostly as educators, inventors, fabricators, and hobbyists. The lowest concentration of responses reflects more peripheral positions in the community, involving procurement officers, managers, legal experts, and students (**Figure 1:** Reported roles in the OH community).

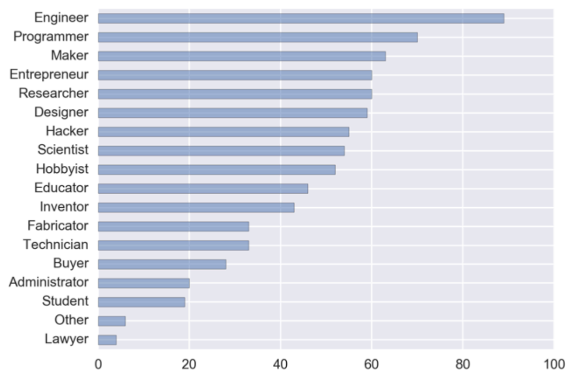

Figure 1: Reported roles in the OH community

OH practitioners report a wide range of experiences. In the graph above, respondents describe themselves in various categories at once. The broader community encompasses a much larger constituency of amateur electronics *aficionados,* academics, mechanical and electronics engineers, and smaller groups of interaction designers and artists. According to the OSHWA surveys of 2012 and 2013, the majority participates in the condition of hobbyists using OH for self-education and personal projects (82% and 10% respectively).

Many participants in the local and the broader community report having downloaded CERN OHL-licensed designs (63%) but fewer have released their own projects (30%) or contributed to CERN OHL-licensed projects (34%). Many respondents have responded positively to the question of "CERN-OHL marketing value." These initial observations suggest the need for further empirical work on license preference and adoption. Based on previous ethnographic research conducted by Murillo in the Pacific region, he observed that flexible copyright licenses, such as Creative Commons, seem to be quite popular despite on-going debate about the inadequacy of copyright licenses for hardware projects. This observation is corroborated by the OSHWA surveys, which report on a majority of designers and engineers using Free and Open Source licenses (around 50% on average for 2012 and 2013 respectively), Creative Commons licenses (34.4% and 37.5%), and public domain for hardware documentation (25.3% and 26.6%). Counterintuitively, most respondents in OSHWA surveys report not having attached licensing information to their design files (49% and 47%). There is evidence, however, this trend is changing with the wider circulation of the CERN OHL, whereas for the years of 2012 and 2013 its adoption was quite small (2.1% and 6.5% respectively). Despite higher-than-average understanding of licensing models and issues, little consensus has been reached regarding the existent alternatives for OH licensing, ranging from copyleft-inspired, such as TAPR and CERN-OHL, to permissive licenses, such as Solderpad. One of the most important historical reasons for the unprecedented level of public understanding of IP issues has to do with the political usage of flexible licenses as circumvention mechanisms to build alternative moral economies. Licenses have, in this sense, being used as a means not as ends for the purposes of collective organisation to build pools of public resources in various areas of academic, professional, educational, and artistic endeavour.

To advance an understanding of the CERN OH community in particular, survey questions were dedicated to respondents' perceptions of social, economic, and legal dynamics. An overwhelming majority defended that "OH advances knowledge transfer." Strong agreement was also expressed with the observation that "OH is a personal reputation building channel for designers." Equally majoritarian was the affirmation that overall research and technology development costs are reduced, development efforts are sped up and shared among various organisations, and highly customisable products are made possible despite their reported small production batches. Documentation is perceived, in general, to be accurate and "openness" is considered responsible for increasing companies' "competitive advantage," driving market prices down.

In the interview material, the debate about "lock-in mechanisms" was framed mostly in terms of independence from suppliers: whereas most responded positively, a few number of small companies reported the existence of new dependency ties with designers of OH products. This complaint seems unwarranted since there are no legal obligations for using one supplier or another. Respondents have observed that, in practice, companies might not make the R&D investment to take up an existent design, shouldering the responsibility for manufacturing it. In various areas of non-critical application, such as in the hobbyist market, prices are driven down in a "race to the bottom" due to accelerated turnover coupled with the absence of quality control. In the experience of a group of engineers working with large-scientific infrastructures "when you order the same product based on the same schematics, the results can be dramatically different from one company to another."

Respondents were more divided around questions of market size and the possibility of revenue generation based on OH services, which points to a common tendency toward the transposition of FOSS business models. The usage of OH as a "marketing channel for companies" has also divided the respondents in two groups, neatly separated by those who hesitated in responding positively or negatively. Respondents hesitated as well when asked if they had experiences with legal disputes to evaluate the OH potential for reducing legal costs. Similar uncertainty was observed with respect to the enforcement of OH licenses and the possibility of generating revenue from support services, despite the observation of OH adoptees in the business of scientific instrumentation who affirmed that, if their organisation decided to open their designs, they "would need to hire one person for 2-3 designers just to do the documentation and support work."

Strong disagreements were more pronounced with respect to the observation that "OH increases designers' workload." In this regard, small companies report not having the means for making the initial investment to examine, modify, and run OH projects for critical applications, including scientific instrumentation. As one interviewee puts it "when designing something new it is quite hard to find someone who appreciates [the] design work and is willing to share development costs."

The topic of "coopetition" surfaced many times in the qualitative dataset, whereas the majority of respondents agreed in the survey "OHSW requires companies to innovate fast in order to stay competitive." This position was corroborated by an early OH entrepreneur who affirmed his company has to "run on a much faster clock speed," which means keeping an accelerated inventory update to guarantee he was ahead of "cloners." His company pushes new open hardware to the market every twelve weeks on average. By taking the traditional path of patenting, he suggested, his company would have to "stand still for, at least, 17 to 20 years."

Some of the key differences we observed in the responses to the survey and the interviews when comparing and contrasting OH and FOSS economies and development models have to do with 1) marginal costs of manufacturing; 2) value chain: inbound logistics, operations, outbound logistics; 3) supply chain: hardware supplier management is much more complex; and 4) regulations, as hardware is subject to significantly more complex (consumer-protecting) norms and regulations, including more complex IP & licensing issues.

DISCUSSION: OPEN QUESTIONS FOR FUTURE STUDIES

In his studies of global climate science, Paul Edwards describes the necessary conditions for sustaining a "knowledge infrastructure" with "support from an enduring community, minimal shared standards, values, and norms; enduring institutions; specialised vocabularies (for data exchange); conventions; theories, frameworks, models; physical facilities and virtual shared resources" (Edwards 2014). Putting OH in a broader perspective, some of its platform capabilities have been worked out, but it has not yet reached critical mass outside the educational and hobbyist domain. There is strong evidence of its growth in many directions on global scales, nonetheless, and ongoing efforts to create a culture of OH development in the sciences with the recurrent "Gathering for Open Science Hardware" (first organised by members of the OH community at CERN in 2016).

From the preliminary "impact of CERN Open Hardware study" it is possible to identify open issues for further research. While some infrastructural elements of OH have been worked out (through the CERN OHL and the CERN OHR in addition to supporting structures for community development of Free Software-based electronics design tools, such as KiCAD), there still remain many open questions. One of the very pressing issues has to do with the need for clarifying the similarities and differences between OH and FOSS: the former is particularly more entangled in complicated licensing arrangements (potentially involving several forms of IP protection); it demands a wider range of expertise (electronics, hardware, mechanical, and industrial design in addition to firmware development) plus commercial involvement in various development phases. Last but not least, FOSS and OH have overlapping but distinct communities (while OH is enrolling new contributors to Free and Open Source development at large). Based on the responses to the question of "tracking" OH initiatives, it is necessary to advance the study of "OH development trajectories" for understanding existent and potential dissemination and adoption issues. Another recurrent question has to do with the need for shared quality standards, testing protocols, and investment in scientific forms of peer reviewing for hardware documentation. In order to establish OH as an innovation platform, it is, in sum, fundamental to diversify the institutional support for further development of basic tools for OH development, testing, simulation, and versioning (see Serrano 2016 for further discussion of this topic). Few OH projects might have the privilege of counting upon CERN as a partner and active collaborator, however it is important to create a much larger support network across educational, non-profits, and for-profit organisations.

The case of CERN OH is key for advancing our understanding of specific OH sociotechnical, legal, and economic dynamics, but it is far from sufficient in itself. In the context of global scientific infrastructures, the specificities we described serve to compare and contrast with the majority of cases we currently have on small OH companies and start-ups in the field of hobbyist and personal fabrication, interactive design, and engineering (self-) education. The experimental character of OH as an innovation platform presents itself, albeit in its earliest phase, in the form of new productive arrangements. For future studies, it is necessary to specify with empirical research these new productive and exchange dynamics in detail *vis-à-vis* frictions and tensions generated in the on-going dispute with IP-based and other well-established forms of technology transfer.

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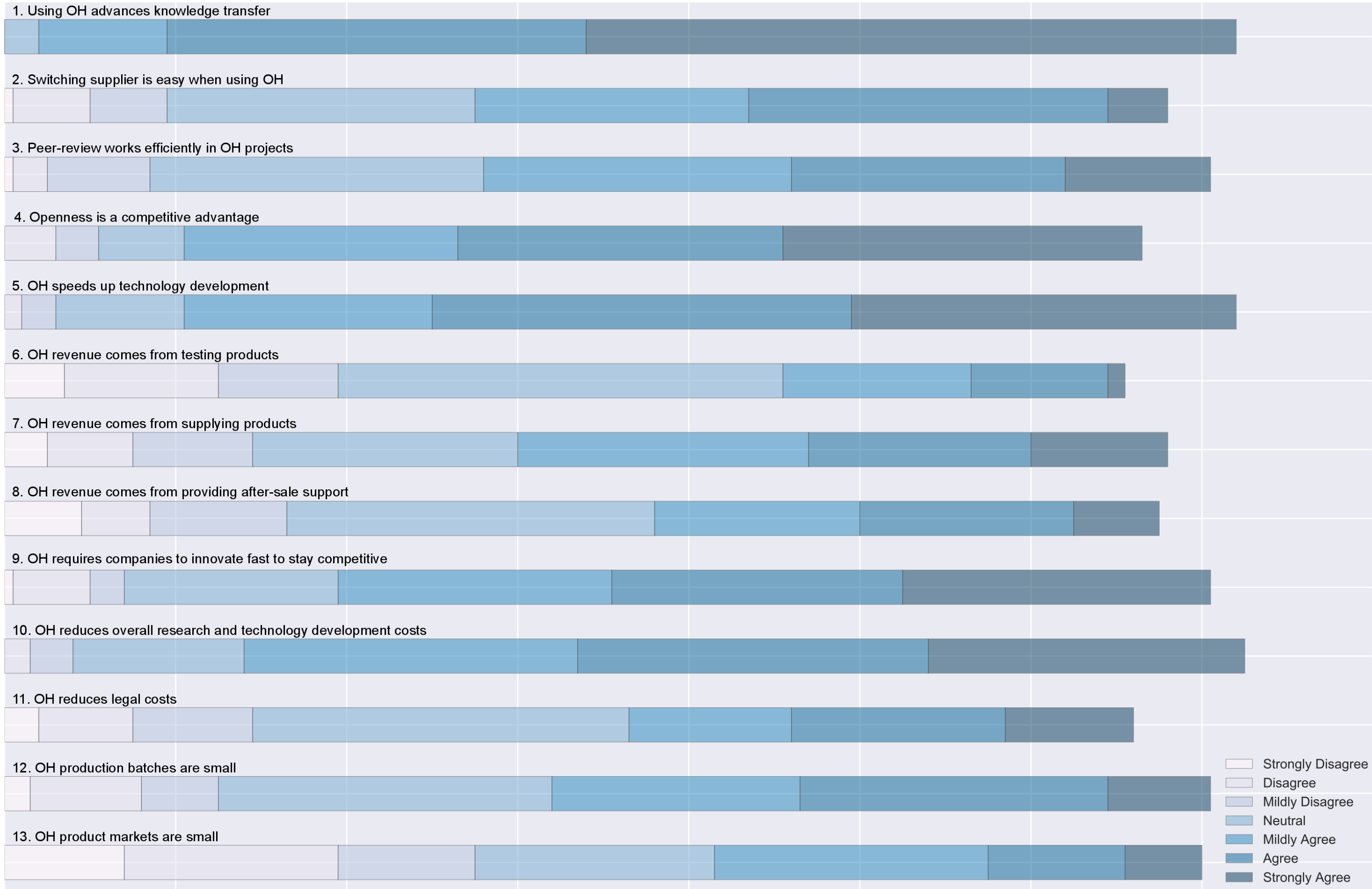

Figure 2a: Respondents' perceptions of common open hardware issues

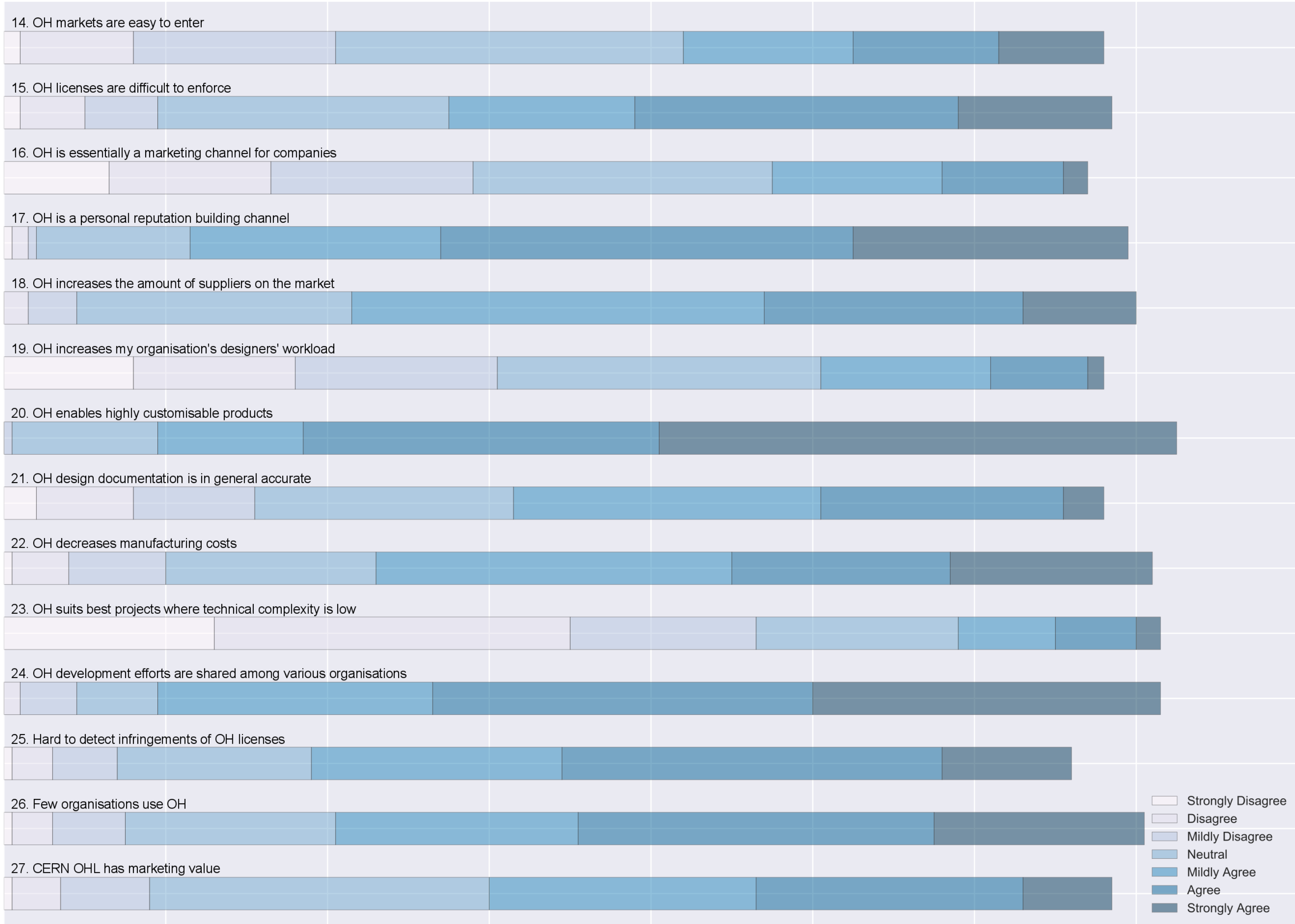

Figure 2b: Respondents' perceptions of common open hardware issues

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