Opening Up the Tools for Doing Science: The Case of the Global Open Science Hardware Movement

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Open science hardware (OSH) is a term frequently used to refer to artifacts, but also to a practice, a discipline and a collective of people worldwide pushing for open access to the design of tools to produce scientific knowledge. The Global Open Science Hardware (GOSH) movement gathers actors from a diversity of sectors advocating for OSH to be ubiquitous by 2025. This paper examines the GOSH movement's emergence and main features through the lens of transitions theory and the grassroots innovation movements framework. GOSH is here described embedded in the context of the wider open hardware movement and analyzed in terms of framings that inform it, spaces opened up for action and strategies developed to open them. It is expected that this approach provides insights on niche development in the particular case of transitions towards more plural and democratic sociotechnical systems.

Key Words:

Open science, open hardware, grassroots innovation movements, sociotechnical transitions.

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INTRODUCTION

Since the late 2000s more and more people all over the world are modifying, tweaking and building artifacts from scratch for different purposes, and releasing the design files to the public domain (Anderson, 2012; Powell, 2012; Kuznetsov & Paulos, 2010). They make use of 3D-printing technology, cheap electronic components, biomaterials and other digital fabrication tools (Fressoli & Smith, 2015; Gibb, 2014; Delfanti, 2012).

Within this currently well-established “maker” or do-it-yourself movement (Nguyen, 2016), a particular subgroup of people making open tools for science, or *open science hardware* (OSH), has gained ground during the last 5 years (Murillo, 2016; Pearce, 2017; Wylie et al, 2014).

The Global Open Science Hardware (GOSH) community aggregates actors from a diversity of backgrounds and expectations, with the common goal of making the open designs of tools for science ubiquitous by 2025 (GOSH, 2018). Since its inception, OSH has gained greater visibility and has received coverage in academic and non-academic press: new educational programs were created, OSH projects have received funding and universities have become interested in its benefits. After three global gatherings, the publication of a manifesto, a roadmap and an action plan, GOSH started decentralizing its activities in 2019 in what seems to be a tipping point. It is therefore worth analyzing the movement’s emergence and main features at this stage, where the previously blurry institutional interface is becoming clearer.

The aim of this article is to report on research about GOSH’s short history as a grassroots innovation movement. The analytic framework is introduced in Section 2 and the methods adopted in Section 3. In turn, Section 4 describes GOSH’s broader *context*, focusing on enablers and opportunities for the emergence of OSH. Section 5 presents the main actors and *framings* that inform the movement and shape its collective action. Section 6 continues with a characterization of the different *spaces* that GOSH practitioners have opened up for OSH development and, in section 7, the *strategies* they use to do it. Section 8 speculates about alternative futures, learning from GOSH’s recent history and the experience of other grassroots innovation movements.

ANALYTIC FRAMEWORK

In this paper GOSH is analyzed through the lens of the *grassroots innovation movements* (GIM) framework (Smith et al, 2017; Hess, 2007). GIM combines concepts from sociotechnical transitions theory and social movements literature to address the particular case of bottom-up knowledge-production civic movements. It also incorporates the concept of *pathways* developed by the STEPS Centre (Leach et al, 2010) to answer the question of how these particular innovation niches can contribute to alternative development routes (Hess, 2007; Smith, 2006).

GIM is a powerful framework to understand how innovation can emerge outside traditionally studied settings like the firm or research institutions; GIM promote social change by developing alternative or new forms of material culture (Hess, 2005). This is applicable to the case of GOSH, a heterogeneous collective with a clear call for social change, producing knowledge and technology outside traditional innovation circuits. Being GOSH claims politically explicit, power

dynamics constitute an important part of the analysis: the social movements component of GIM illuminates this aspect.

The transitions component of GIM gives it a systems perspective, useful to analyze change dynamics as an interplay of multiple factors in the sociotechnical configuration. It is a co-evolutionary, systemic approach that understands sociotechnical change as the result of interactions between multiple levels in the sociotechnical system (Geels, 2019; Geels 2002): the innovation niche or GIM, the regime (or status quo, the established way of working) and the context or landscape. Strategic niches, or those with potential for fostering change, should be able to (i) articulate their expectations and visions in a robust and specific way, (ii) build deep and broad social networks, (iii) count with key intermediaries to exchange lessons and (iv) favor secondary learning in key areas, adapting their expectations and actions accordingly. The systemic approach turns out to be useful for studying a movement like GOSH, aiming to transform deeply rooted practices at the systems level.

Combining these approaches, GIM framework proposes to analyze four complementary dimensions (Smith et al, 2017): i) *Context*, or the historical circumstances in which GIM emerge; ii) *Framings*, or shared meanings, interpretations and narratives that hold the movement together and orientate its activities (Snow et al., 1986); iii) *Spaces*, or the collection of sites and arenas – physical, institutional, organizational and cognitive – where rules are different from the regime (Kemp et al., 1998; Seyfang and Smith, 2007) and allow GIM to actively open up material activity; iv) *Strategies*, or how these spaces are opened up in terms of the ability to generate *networks and intermediaries*, the *repertoires of action* or forms of organization developed to open spaces (Tilly, 2008) and the *mobilization of resources* (McCarthy & Zald, 1977), both material and non-material (Oberschall, 1973).

METHODS

The analysis in this article is based on the results of a study carried out during late 2018 and early 2019. Thirteen semi-structured interviews were conducted with GOSH participants, three in-person and the rest through video calls. Interviewees comprised community co-founders, all co-organizers from the three global community events and key participants (Table 1).

Table 1

Role, precedence, and description of interviewees

Role	Description
Co-founder	Academic researcher, open bio economy advocate (UK)
Co-founder	Community organizer, environmental health advocate (US)
Co-founder	Entrepreneur, open technologies advocate (US)
Co-founder	Director of a higher education initiative (Switzerland)
Co-organizer 2016	Independent researcher, community organizer (Switzerland)
Co-organizer 2017	Researcher

Co-organizer 2017	Academic researcher (Chile)
Co-organizer 2017	Academic researcher, community organizer (Cameroon)
Co-organizer 2018	Collaborator in a higher education initiative (China)
Key participant	Independent researcher, micro engineer (Switzerland)
Key participant	Independent researcher, community organizer (Chile)
Key participant	Academic researcher (Argentina)
Key participant	Academic researcher (UK)

The selection of key participants was carried out considering active participation in significant community milestones such as the writing of the community roadmap in 2017 or the definition of the community action plan in 2018. This information was cross-referenced with the replies of founders and co-organizers to the question “*Who do you consider a key participant in the GOSH community?*”. Material from interviews was complemented with other public sources such as press articles, community documents, data from the online GOSH forum and social media.

The qualitative analysis presented in this article was conceived as a preliminary stage towards understanding OSH contribution to building research capabilities. As such, this first approach doesn’t aim to obtain generalizations or build theory; it is limited to presenting the particular case of the GOSH community and deepening its understanding within the concepts of the proposed analytic framework. The analytical categories were embedded in the interviews questionnaire following a chronological approach, intended to reconstruct the experiences of the interviewees at different stages of their participation (see **Appendix** for questionnaire used in interviews). The coding of materials was assisted using RQDA, an open source Computer Assisted Qualitative Data Analysis Software (CAQDAS). As a contribution to the community, an [outreach article](#) on GOSH’s history was written and shared on the GOSH website.

CONTEXT – EMERGENCE OF THE OSH MOVEMENT

Since the early 2000s a much wider spectrum of the public started tinkering with hardware, boosted by the upsurge in 3D printing (Söderberg, 2013), the irruption of educational electronic platforms (Hertz, 2011) and the availability of low-cost electronic components. Emblematic projects include the RepRap 3D printer (de Bruijn, 2010) and the Arduino board in 2005, subject of controversy over its origin in relation to project Wiring, born in 2003 (Barragán, 2016). The first edition of MAKE magazine – reference for the maker community worldwide – and the rise of new business models like Adafruit or Sparkfun (2003) had significant impact in consolidating both a community and a market. Moreover, the increasing popularity of practices from the hacker community, with numerous new physical spaces for open innovation such as makerspaces and fablabs, facilitated access to digital fabrication tools for a wider audience (Maxigas, 2014).

Since these early initiatives, making open hardware has become more accessible. There have been initiatives pushing for an open source software “toolchain” for open hardware (Murillo,

2018; Serrano, 2017) to enable more users to design. New business models have emerged, offering services of “design for manufacturing”, to facilitate the process of moving from do-it-yourself prototypes to industrial products at scale.

The boom of do-it-yourself projects, coupled with the upsurge of online platforms where information and knowledge circulate freely, favored the sharing of designs and aggregation of practitioners in communities of practice (Benkler, 2006). Open Hardware (OH) as an encompassing concept was first defined in 2010 after the first open hardware summit (Open Source Hardware Association, 2013), shortly after the first open hardware license was created in 2007 (Ackermann, 2009), followed in 2008 by the CERN Open Hardware License (Ayass & Serrano, 2012).

Open hardware for science encompasses any tool used for scientific research, including standard lab equipment as well as auxiliary materials such as sensors, biological reagents, analog and digital electronic components (GOSH, 2018). In most cases it builds on the enablers mentioned above: the combination of 3D-printed parts, rapid prototyping boards and cheap electronic components reduces the costs of science tools by 90-99% in some cases, when compared to proprietary equipment with equal functionality (Pearce, 2014). Although most projects work with conventional lab equipment, OSH also comprises auxiliary materials such as biological reagents, and both analog and digital electronic components. The designs are shared through specific publication venues but also through community platforms; improvements in accessibility have enabled citizen-scientists and scientists without engineering backgrounds to onboard and build science hardware too.

Besides these infrastructure opportunities, ideas around citizen participation and science democratization have played an important role in the emergence of OSH as a movement. In the beginning of the 2010s two environmental disasters, one in Japan -Fukushima in 2011- and the other one in the US -DeepWater Horizon in 2010- exposed the lack of transparency and performance of governments for providing accurate, updated environmental information to the public (Figueroa, 2013; Dosemagen, 2019). The increased availability of low-cost tools, combined with this lack of response from the scientific and political spheres opened up a window of opportunity for new forms of grassroots knowledge production. Citizen science, defined since the 1990s but reinvigorated during this period, witnessed a growth of projects and platforms gathering citizens' efforts for data collection, in particular in the natural sciences. More recently, this paradigm of citizen-scientists as data collectors for research projects started to face some criticism, demanding more empowerment of non-academics in citizen science projects (Resnik, 2015) and proposing alternative practices of community-based science (Dosemagen, 2019; Liboiron, 2017; Wylie et al, 2017). One of the interviewees, GOSH co-founder and US-based community organizer, recalls how around the 2010s in the US a wave of “civic technology” initiatives constituted a major trend: “in the United States specifically there was also a movement around OpenGov and Gov 2.0 back in 2010 [...] in a decade span we saw enormous steps in how people were thinking about creating and using technology”.

In the academic world, ideas from the open-science movement were gaining significant ground (Albornoz et al, 2018) and expanding to other domains besides open access and open data (Ballell, 2013; Hylén, 2006). Another interviewee, GOSH co-organizer and academic researcher, shares her perceptions on this shift: “I think the change has been driven by established

institutions and norms about knowledge, realising that they not only need but want these other kinds of knowledge”. Criticism of hidden power dynamics in open science practice has called for developing more inclusive and situated open science and science in general (Chan et al, 2019; Okune et al, 2018; Albornoz & Chan, 2018, Nature Editorial, 2018). More recently, the increasing adoption of open-science strategies at the policy and institutional level lowered the entry level for open hardware discussions to happen within institutions; the draft of the UNESCO Recommendation on Open Science now includes Open Hardware in its definition (UNESCO, 2021).

This shift towards promoting more diverse, inclusive and participatory systems of knowledge production both within academia and civil society contextualizes the emergence of the GOSH community. Most interviewees recall that OSH initiatives consisted of only a few isolated cases around 2010, but by 2015 the situation had changed completely. Projects multiplied in the most diverse contexts, with new initiatives appearing not only in the US or western Europe, but globally. This was the scenario when the conversations about creating an OSH community started taking place, in 2014 (Fig. 1).

*Figure 1: Timeline of events around the emergence of GOSH movement and its subsequent milestones (prepared by author, *: based on literature review **: from interviewees)*

FRAMINGS IN OSH

GOSH founders and participants come from a wide variety of backgrounds, bringing in multiple ideas that converge in a main proposal stated in the GOSH manifesto (GOSH, 2016). In the

following subsections I describe these framings in terms of actors, their motivations, how they problematize the scenario and their visions for OSH.

Open science

GOSH finds a significant number of its advocates in **researchers within academia**, mainly from the natural sciences. Originally with most researchers from Europe and the US, the distribution of the community intentionally changed after the first gathering in 2016, incorporating a significant number of participants from Africa and Latin America.

Academics in GOSH express that one of their main **motivations** to “*go the open-source way*” is a problem their predecessors were able to solve (von Hippel, 1976): tweak, repair and adapt science tools to fit their very specific research needs. On the contrary, nowadays science tools are very difficult to fix, customize or fully inspect, due to patent restrictions and closed designs.

This **problematism** is not far from the general claims of other communities advocating for a more active role of users/makers of technology, such as Right to Repair: “*We want to repair the stuff we own, so we can use it for longer*” (Opsomer, 2020) or the Maker community: “*The best attribute of a well-run makerspace is the sharing of skills and knowledge*” (Hatch, 2014). However GOSH researchers understand that the barriers faced by users of science tools are particular and derive implications for the knowledge-production system and for society as a whole. One of the participants, GOSH co-founder, independent researcher and entrepreneur from the US, describes this particular niche: “In the Open Hardware conference people aren’t talking about how we actually impact science; and in open science conferences everything is about open access to papers”.

Not being able to access the blueprints of science hardware translates into significant delays, costs for researchers and non-functional equipment piling up in university labs. Lock-in with vendors also represents a risk for research as companies may go out of business, drop a product line or lose specialized staff. An interviewee, Swiss micro engineer and interdisciplinary researcher, frames this as a broader problem related to academic culture and power dynamics inside universities, envisioning that “*in 20 to 50 years there’s not going to be any research that is not based at least partially on open hardware [...] all these hierarchies and closed research groups and competition, is a complete mess*”.

OSH is **envisioned** as an enabler for “better science”: designs can be inspected or peer reviewed transparently, avoiding duplication of efforts, getting better results, facilitating reproducibility and potentially boosting hardware builders within academia (Parker et al, 2021). Some of these envisioned benefits are indeed reported in the literature (Pearce, 2014), while others such as the potential benefits for hardware builders are still “work in progress” for the academic OSH community. Although dedicated publication venues like the Journal of Open Hardware are run by the community, there is still discussion on how to engage universities and push for recognition of OSH-related work (Arancio & Molloy, 2021; Stirling, 2020).

All interviewees mention the ability to customize tools for their own different needs as one of the main motivations behind their OSH practice; most hands-on workshops during events are also related to this activity either providing basic hardware skills, showcasing adaptations or

discussing documentation (GOSH, 2019). In the community roadmap (GOSH, 2018) practitioners also present OSH as an opportunity to save costs of repairing and buying equipment, seizing capacity of in-house personnel, fostering collaboration and increasing the quality of education. In words of one of the interviewees, GOSH co-organizer and part of an open education initiative at a renowned Chinese university: “The research system is not ready for the future, there are many resources wasted: departments compete with each other when they could be making significant change by sharing”.

OSH is therefore communicated as a more efficient and convenient way of doing science, for academics, students, institutions, companies, but ultimately for society, who would benefit from accelerated innovation in science and increased access to more and better knowledge around the world.

Environmental justice, cognitive justice

Environmental justice (EJ) – referring both to a social movement and a social sciences body of literature – deals with the question of how environmental benefits and damages are distributed within society, but more widely, of how communities can participate equally in environmental policy discussion, and their practices be recognized and valued (Agyeman et al, 2016). As a result, it calls for situating knowledge, practices and assessments, ensuring community recognition, and identifying barriers for participation. As a movement, it also holds a tradition of community-empowering practices through grassroots monitoring activities and knowledge-production processes (Roberts & Toffolon-Weiss, 2001; UCC, 1987).

Closely related, cognitive justice (CJ) calls for fraternity between forms of knowledge (Visvanathan, 2006), claiming that our society privileges scientific knowledge over other forms of knowledge, which has undesirable social, economic and political consequences for communities (Mgbeoji, 2014).

EJ and CJ are frequent topics during GOSH meetings. Main actors include **activists, NGOs, social scientists** who see in OSH a powerful tool to foster change in society, achieving goals beyond academia and conventional ways of knowledge production. Their main **motivation** relies on the fact that the majority of the population, often subdued to environmental or other types of injustices, has restricted access to science tools, and therefore can not use them for their own research or education needs.

The existence of a closed, patented model for science tools is framed as the driver behind concentration of technology design in small, privileged groups, creating a power asymmetry between tools creators and tools users. This asymmetry is **problematized** in different ways:

- (a) Patents promote concentration of design and manufacturing processes, which results in prohibitive costs and unavailability in peripheral countries (e.g., imports restrictions);
- (b) When technology is available, people are not always able to effectively use it in a particular context or for a particular need that was not considered in the original design;

- (c) When technology is available, most of the time it is not accessible for underrepresented groups of people, as they were not originally considered as users.

The closed model is therefore seen as reproducing systemic injustice(s). Lack of access to knowledge production tools for less represented sectors means more dominant – western, white, male, academic – knowledge produced, while drowning representation of non-hegemonic groups – low-resource, indigenous, women, non academic –.

Related to the concept of undone science, being tools mostly dominated by academics, governments or markets, the knowledge produced is only knowledge that is interesting to those actors. As communities do not have the means to produce their own knowledge, their agendas are disregarded.

These ideas have become a backbone ethos of GOSH, as reflected in the community manifesto: People have a right to knowledge, and thus a right to the tools to gain that knowledge. Users align their technologies with their values by becoming creators [...] Open science hardware is open to everybody, without considerations of scholarly background, country, race, sex, or religion and does not tolerate discrimination on these grounds [...] Open science hardware puts local knowledge in action and contributes to cognitive justice [...] You don't have to be a "biologist" to do biology, or have a degree to do research [...] GOSH empowers people to pursue research based on the needs of their communities (GOSH Manifesto, 2016).

EJ ideas are explicitly mentioned by interviewees from non-academic backgrounds, besides appearing in community documents such as the GOSH roadmap and in documentation of events. But they are also deeply embedded in material practice, including the significant number of OSH projects related to community environmental monitoring, community workshops for assembling hardware or sessions for discussing how to work with community environmental data (GOSH, 2019).

These values and ideas have become the foundation of the diversity strategies that all interviewees identify as what makes GOSH different from other communities in the technology and academic spaces.

Appropriate technology and critical pedagogies

The term 'appropriate technology' (AT), coined in the economic debates on development and assistance of the '60s (Smith et al, 2017), implied a set of shared characteristics: low-cost technologies, manufactured with local materials, employing local labor, small scale, without requiring high-level expertise or hegemonic education, collaborative or collective development, no use of patents or other intellectual property instruments. In some contexts, AT practitioners experimented with social participation for communities to define their own problems and experiment with their own solutions (Fressoli & Arond, 2015). In South America in particular, AT ideas were influenced by the ideas of critical approaches to pedagogy, where education is understood as a tool for critical thinking and political activism (Freire 1973; Fals Borda, 1979).

Many participants in GOSH are **educators and activists** with a background in critical pedagogies. These actors **problematize** the closed science hardware system as an impediment for access to technology, favoring one-size-fits-all solutions that do not take into account the peculiarities of different contexts. Proprietary hardware is framed as one of the causes for asymmetrical north-south access to science and education, reinforcing technological dependence, constituting a major challenge for education, job insertion and development of local solutions to community problems. A GOSH co-organizer, social scientist and founder of a makerspace in Africa highlights his motivations for founding AfricaOSH: “we should avoid to replicate simply what is coming from oversea [...] we have to appropriate, to contextualize and see what is good for us or what is not good for us”.

The **visions** within this framing revolve around OSH as a way of democratizing science and technology, reducing the technology gap and contributing to development. Interviewees from African or Latin American communities, in concordance with previous studies showing connection with post-colonial and economic development issues (Kera, 2015), frame OSH as an avenue for underprivileged groups to be able to access, learn and use scientific tools for their own research, education and development needs.

Hacker culture, trans-hacktivism

The hacker movement, which informs most open and collaborative, peer-to-peer communities (Benkler, 2006), is commonly associated with an ethos based on liberal values such as freedom of information and expression, right to privacy, meritocracy and the power of individuals (Coleman, 2004; Levy, 1984). However, the articulation of these concepts takes different shapes through interaction with other backgrounds, creating a set of related but different expressions around property, work and creativity (Coleman and Golub, 2008). One of these expressions, trans-hacktivism, presents intersecting points with previously described framings: it combines concepts from hacker culture with intersectional feminism and queer theory, critical pedagogy, technology decolonization and autonomism.

Artists, biohackers, trans-hacktivism in GOSH work in the continuum between craft, science and art, usually participating through hands-on workshops or performances during the gatherings. Many of them are also part of biohacking communities, like Hackteria or DIY Bio, or more institutional initiatives like the iGEM competition or the MIT Bio-summit.

Trans-hacktivism constructs their main **problematization** around the dominance of one perspective embedded in technology design, its normative power and the consequences for individuals. Hegemony in technology design restricts possibilities for alternative visions of science and technology to emerge and grow. Usual topics include normalization of identities and bodies (Forlano, 2016; Tsang, 2017), loss of privacy due to surveillance capitalism, patriarchal expressions in technology (Davis, 2016).

The workshop “The use of the speculum in a practical way - Transfeminist Hard Lab” took place during GOSH 2018 global event, showing some of these ideas in practice:

“The main hardware is the body”. The proposal of the session was to discuss the transHackfeminism context and the intersection with OSH. There were two workshops

proposed by Paula Pin: Coñurt (making yogurt with the vaginal lactobacillus) and the easy vinegar test for HPV. The session was based on an extended introduction about how transfeminist are having more autonomy on ecology and gynecology to focus later on the body itself (GOSH, 2019).

As exemplified in the documentation of the workshop, trans-hacktivists value collaboration instead of competition, self-education, experimentation and failure as part of the experience of creating technology. Their **vision** frames OSH as an instrument towards developing autonomous infrastructures, decolonizing technology and decentralizing power.

SPACES FOR OSH

In the following subsections I describe four different spaces opened up by GOSH practitioners to develop their activities.

Community science projects

Community-based environmental monitoring – requiring low-cost tools that are easy to use and share, and transparent data-generation processes – is a fertile ground for OSH development. Some early examples include Public Lab, a non-profit running projects using OSH and community-organizing methods for environmental monitoring, and Safecast, a crowdfunded community science project that measures radiation using OSH. Both appeared in response to a lack of accurate official information on the impact of environmental disasters, and used OSH to build, learn and use low-cost-aerial photography kits and geiger counters respectively.

The biohacking community constitutes another significant space receptive to OSH. Biohacking, DIY bio or Garage Bio is defined as a movement of people conducting life sciences outside of traditional professional settings such as universities and corporate labs. Acquiring tools and equipment to do science outside academia is expensive and difficult, in particular as individuals. One of GOSH co-organizers, independent researcher and community organizer in the global biohacking community describes the main purpose of their first workshops and activities: “Since the very beginning [the movement] was mostly in fact focused on making laboratory equipment because some of the tools, although we say we can do these genetics and save the planet, they were not really accessible”. [Hackeria](#) and [DIYBio](#) are possibly the most important biohacking networks worldwide: communities that produce, test and put into practice artifacts developed by enthusiasts globally. Developments go from simple DIY incubators to PCR machines, including complete open sets for biology labs.

Academic researchers

The open-science movement focuses primarily on open data and open access to publications; the broader open-hardware movement hosts discussions oriented to the maker community. In the middle of both, GOSH attracted academics who were using or developing OSH marginally in their institutions, and didn’t find their place in those related communities.

One of the spaces for OSH in academia is found among highly specialized research and

engineering teams developing science tools or cutting-edge research. This group includes researchers who reverse-engineer proprietary tools, modify them and create their own versions using open licenses, as a way of fostering adoption and accelerating innovation. As an example, the Laboratory for Bio and Nano instrumentation at EPFL, Switzerland, has documented developments on open atomic force microscopy (AFM). An interviewee, GOSH co-founder and academic researcher at a top university in the UK describes how OSH poses different challenges for academic researchers: “There were several initiatives in the DIY bio field which I had awareness of, that were inspiring from the educational side but as a lab experimental scientist I saw the limitations that designs could offer”.

Another space was opened by researchers working in applied sciences with small budgets, where proprietary tools are not an option. OSH is a way to cover greater geographical areas or increase the number of samples analyzed with a limited budget. It is also a way to customize tools to highly specific contexts and research questions that were initially not considered by designers.

Recalling the motivations to create GOSH, the interviewee mentioned above also points out how “I felt frustrated by the cost of stuff I was using for my experiments and the fact (I was working with mosquitoes) that equipment was inaccessible to people actually living in areas where mosquitoes disease are endemic”. These arguments are also mentioned by interviewees from Latin America and Africa, and are explicitly mentioned in all community documents besides constituting the backbone of community initiatives that are part of GOSH.

Education and social innovation

OSH gained spaces where educators with a critical view of traditional teaching methods started experimenting with open technologies for learning. This happened both inside and outside institutions of formal education.

Within schools and universities, usually oriented towards facilitating STEM education, OSH is used to develop challenge-based learning activities, accelerate experimenting and prototyping in the classroom. LEGO2NANO is a project started in 2013 with the support of the London Centre for Nanotechnology and the LEGO Foundation, when a group of PhD students from China and the UK took up the challenge of building an open, low-cost AFM. With the goal of bringing nanoscience to high-school classrooms, students were able to put together a working prototype built from LEGO, Arduino, cheap 3D-printable parts and consumer electronic components. The project inspired others worldwide, who started implementing OSH in the classroom (Heradio et al, 2018).

One of the participants, GOSH co-founder, director of a Swiss open education initiative, recalls the origins of LEGO2NANO:

I'd been in touch with people from Lego Foundation, they were talking about serious play and the importance of hands on learning [...] The students really progressed quite far on making an open source AFM. We got a lot of attention and we repeated it the next year, and the next year. What was interesting was this idea that we could actually do science hardware projects with students and really get somewhere significant in a short time.

Another space was opened by numerous educational projects run by NGOs, communities and entrepreneurs around the world who started using OSH as a bridge between education and social innovation. [Kharkana](#) and [The Tech Academy](#) are extracurricular education projects in Nepal and Bangladesh respectively that promote STEM education through collaboration, experimentation and play. Their students come from different backgrounds; in the case of the Tech Academy, education is granted for free to students with families who can not pay for it. Both initiatives use a learning-by-doing approach, intended to foster creativity in students while they acquire digital skills, applying them to developing solutions for their local problems. Students' projects often participate in international innovation contests, many times related to the UN Sustainable Development Goals.

Artists

Artists working in the interface of science and art use OSH tools in different domains: biomaterials, textiles, audiovisual experiences and even inter-species communications. OSH gained a space here as its rapid-prototyping methodology enables experimentation at low cost, available documentation allows artists to learn how tools work and data is produced, and because information behind paywalls becomes a real challenge to most artists, who are not affiliated to scientific institutions.

[Interspecifics](#) is a project born in Mexico that defines itself as a “nomadic multispecies collectivity experimenting in the intersection between art and science”. Among other activities, it transforms electric signaling from different species into audible sounds. Not having any affiliation with a scientific institution, academic publications are usually not accessible for the group: the project relies entirely on openly available knowledge. As a way to give back, they completely documented their hardware and other developments in the open.

STRATEGIES FOR OSH

In this section I present the main strategies GOSH develops to pursue its vision and open spaces for its activities, categorized into three main groups: *networks and intermediaries*, *repertoires of action* and *mobilization of resources*.

Networks and intermediaries

GOSH is a diverse **network of networks** with nodes in academia, civil-society organizations and the entrepreneurial world. This configuration includes non-profits, funding institutions, research institutes and universities, makerspaces, artists, social innovators and educators worldwide (Fig. 2).

The network acts as a platform for increasing visibility and communicating projects' and nodes' activities at the international level. These include presentations in academic and non-academic venues, press articles (Brazil, 2018), new residencies and gatherings announced via the community blog, projects promoted via the global community social media accounts. Regional gatherings usually make use of the global community channels to amplify their message through

networks with a diversity of audiences.

Besides internationalization and widening audiences, nodes within the GOSH network exchange information through **key intermediaries**. Lessons shared are technical but also organizational. Almost all interviewees mention developing different degrees of collaboration, in particular overseas: researchers from Germany have been invited to Chile to run [workshops](#) at universities, bringing not only hardware but also a reproducible methodology that can later be appropriated by locals. Researchers from the UK [collaborate directly](#) with GOSH participants and organizers in African countries.

Figure 2. Distribution of GOSH initiatives worldwide categorized according to spaces (compiled by author based on public records and interviews, [interactive version available](#)).

Repertoires of action

The main strategy developed by GOSH during its first three years of life was organizing **global gatherings**. The meetings are used as an instrument to deliberate, learn, make and define the values, strategies and actions for the collective to move forward. Since the first meeting, each gathering was used as a starting point for elaborating **collaborative strategy**: the manifesto in 2016, the roadmap in 2017 and the action plan in 2018. The methods used for achieving it are openly documented, and replicated in the new instances of events emerging in different parts of the world. One of the interviewees, GOSH co-founder from the US, refers to this strategy in particular: “it’s bringing the question ‘*What is open science hardware to you?*’ to different sorts of cultural locations in the world and letting that question be answered in whatever way it is answered in that place”.

The intentional mechanisms put in place to ensure **diversity** of participants during the gatherings can be considered a strategy in itself. Diversity allows the collective to have “representatives” from almost every area inputting their visions into GOSH. This turns GOSH into a **deliberation**

space and reference, as can be seen in the growing requests for interviews from the press and cites [in other communities' documents](#).

An interviewee, who was part of the GOSH founders group, comments on the difficult aspects of this strategy:

I think the challenge is then also the kind of bubble effect, that it doesn't become an echo chamber like: we have these values, so it's us against the world; what happens if you bring in people who don't have those values? How is that going to work?

Diversity also allows the community to “tailor” its message according to the audience, being able to frame OSH differently according to the context. Researchers actively promote OSH into broader Open Science conversations (*‘there is no open science without open science hardware’*), activists promote the appropriate technology and democratization aspect, artists evoke its transparency and potential for developing autonomous infrastructures.

Another important component of the gathering strategy is the **combination of material and reflexive activity**. Seventy percent of the program is defined on demand during the gathering, combining hands-on workshops on building and using OSH with discussion sessions on topics chosen by the audience and instances of group deliberation. Different people occupy different roles according to their interests, contributing with their different perspectives. Results of community deliberation are translated into **documents available online for collaboration**, which amplifies the message online, acts as a legitimization strategy by enlarging the contributor base and is useful as a communication piece itself, promoting the movement's activity.

Promotion of **impactful developments** or ‘use cases’ constitutes another important strategy. The OpenFlexure microscope is currently presented by the community as a successful use case of OSH. It was created by academics from the University of Bath who developed a collaboration with STICLab, a makerspace in Tanzania (Stirling and Bowman, 2020). The tool has been completely replicated by the partners in Tanzania using locally available materials, who are now testing it as a method for easy, quick and low-cost detection of Malaria. This kind of artifacts connect actors globally through powerful narratives, condensing values of the community and constituting effective communication pieces. The OpenFlexure microscope has been featured in mass media press, besides appearing in news from academic and community circles.

The definition of a **research agenda** on OSH and the creation of [community publication venues](#) is another strategy related not only to reflection on the movement activity but also to seek legitimacy within academic rules and demonstrate the superior performance of OSH versus proprietary equipment.

Mobilization of resources

Financial support has been mainly mobilized through **access to grants** from US-based foundations in the open-technologies space. The gatherings are free of charge for participants, although there is a suggested fee for contributing to cover other participants' costs. Financial support for GOSH activities in Latin America comes from grants from an Iberoamerican funding agency for science and technology. One of the participants, Africa OSH co-organizer, recalls that the conference received personal funding from the organizers group in order to happen: “The

main idea was to support Africans living in Africa to attend the event, and that is a big challenge”. Funding for project development also comes from **crowdfunding** activities, which also help gaining visibility.

As many participants of GOSH work at universities or community spaces, fablabs, community makerspaces and other **venues** are usually accessible to the community for low or no cost. Hardware materials, when not coming from grant money, are usually paid for or obtained through **sponsorship** from electronics suppliers.

In terms of non-material resources, GOSH is entirely run on volunteer work, on which it depends for different functions. **Leadership, organization and communication skills** are key resources for GOSH development, which have been mobilized mainly from GOSH participants that also happen to be community organizers. As an interviewee, GOSH co-founder points out: “We had people in the room who knew how to do this [collaborative, unconference] stuff”. **Technical skills** are required for building hardware; these usually come from experts in the community that contribute to other projects through the GOSH forum online or directly participating as key intermediaries, transmitting lessons to other projects or connecting with other experts. Technical expertise is recognized through credit in designs or scientific articles.

Trust is another important resource mobilized mainly from original GOSH founders, which enables access to grants but also visibility through articles in the press and social media. Access to prestigious networks acts as a resource of **legitimacy** for the outside world. Interviewees mention that ‘serious’ actors being involved in GOSH (highly visible universities, non-profits, research institutions, researchers) contributes to supporting their daily work at their home institutions.

Positioning GOSH as part of other movements mobilizes resources in terms of **shared culture and knowledge**: it attracts people from those communities, provides vocabulary and narratives, facilitates lessons and increases visibility. This strategy can be observed in academic press articles where GOSH is presented as a subgroup of the open-science movement, or when presenting to a more maker audience, as a branch of the maker movement. Shared knowledge is also relevant, for example when business models of open-source software are taken as a point of departure to study potential business models for OSH.

The contact with the appropriate technology movement, feminist, post-colonial studies or environmental-justice movements are some examples of mobilization of **historical tradition and ideology** resources that help approaching specific actors at the local level. This is the case of GOSH initiatives linking [OSH, agroecology and social movements](#) in Latin America.

GOSH AS A STRATEGIC NICHE

The analysis of GOSH as a grassroots innovation movement provides some basis for considering it a strategic niche with the potential for influencing the regime of patent-based scientific tools and knowledge production.

GOSH's collective ideas, though informed by multiple and diverse actors, are **clearly articulated** in open, collaborative and living documents and are communicated to the outside world through independent but also massive media and press. This articulation has evolved and gained specificity through the years, as can be seen with the evolution of public documents on collective strategy: from the manifesto to the roadmap to a concrete action plan.

GOSH participants have the ability to build **networks**, which on one hand are broad: the collective is linked to actors in the local, regional and even international level; actors include practitioners but also companies, academic institutions, civil-society organizations. On the other hand, these networks are also deep: participants are able to mobilize different kinds of resources from them through a diversity of strategies. The presence of **key intermediaries** is evidenced by the multiple exchanges between participants, both for technical and organizational skills exchange.

The evolution of GOSH activity presents evidence of **secondary learning**, systematizing lessons and adapting their actions, expectations and strategies based on evidence. The decision to become a global movement after the first gathering came after a self-evaluation that pointed out the lack of diversity in participants; the decision to engage with more industry-related actors in the third gathering in China, in response to a perceived need from the participants in Chile and other discussion forums to scale their projects, the decision to decentralize activities in order to avoid burnout of key members of the movement during the last gathering; all of these show how actions in the movement are adaptive.

Futures and open questions

During 2019 there was no global GOSH gathering: participants started organizing regional and local activities while the conversation of governance, sustainability and the future of the movement slowly started taking place. The analysis makes evident that framings informing GOSH are diverse and some of them are more radical in their demands than others. It also provides some material for understanding GOSH's current situation and speculate about possible futures. Going back to the concept of **alternative pathways**, how differently will these diverse ideas that inform GOSH influence the regime?

Lessons learned from historical analysis of other grassroots innovation movements, though not transferable, can still provide some insights. In his study of the trajectory of the organic food production niche in the UK, Smith (2006) sheds light into the dialectic nature of niche-regime relationships. Outside the niche, diverse actors in the sociotechnical system appropriate niche practices differently, leading to its fragmentation, incremental innovation and renewed alternatives hosting more radical cores. Smith suggests policy should encourage this dual nature of niches, both radical and reforming.

As mentioned, some OSH practices are easier to be absorbed by institutions than others. How would this differential appropriation affect GOSH as a collective? One possible scenario, not too far away into the future, could involve top university labs and research institutes becoming equipped with open science hardware. Their design and engineering curricula includes open models of hardware production, and fablabs or makerspaces turn into "tech support" and

developing hubs for in-house researchers. In this scenario, most hardware is produced by companies who publish the designs online under open licenses. The benefits start showing in terms of coordination of research efforts, repairability of technology and acceleration of innovation. However, designs are still difficult to replicate in some parts of the world where components are not available. As the new designs become a de facto standard for research, maybe even certified, in countries with low investments in STI researchers still depend on manufacturers in the global north, widening the knowledge gap. Documentation is published but is still unreadable for non-experts or non-English speakers, so the promise of inclusion of more diverse actors is not materialized. In this conservative scenario of OSH becoming default, GOSH could start fragmenting. It can disappear if there is no one to embody the new demands; but the existence of more radical framings related to appropriate technology, critical pedagogies and environmental justice in GOSH opens the possibility of reconfiguration. Some participants move away, as their demands are satisfied; those who remain put the previously more radical claims in the center: OSH must not only be ubiquitous, it must be also accessible for everyone. The change in framing opens up new spaces and strategies to pursue the reconfigured goal.

Lessons learned also point out that more radical niches have to “prove” more significant benefits in order to influence the regime, but that this is not a static process: how radical the niche is perceived to be and how important its benefits are, change with time and with the emergence of tensions in the regime. Which tensions in the regime can be framed as opportunities for OSH? Is it the context of a global COVID-19 pandemic, where the patented model of production leaves the world’s hospitals and workers short of vital tools, a tension strong enough to open an opportunity?

In an imaginary pandemic scenario where OSH is the default practice, the designs of certified Personal Protective Equipment (masks, goggles, garments) and medical/laboratory equipment (ventilators, PCRs for testing, tools for vaccine research) are openly released – some suppliers are [already doing it](#) – and available online. Using these public specifications, industries that produce other similar goods can [reorient](#) their processes more easily to fulfill some of the demand. Fablabs and makerspaces can quickly grab PPE designs and start producing for their communities and local hospitals. Differently from now, makers don’t have to reverse-engineer but can adapt already tested and safe designs, saving precious time in coordination and production, avoiding inefficient side-effects such as governments trying to [homologate](#) DIY designs on-the-go. OSH as a default also means more laboratories around the world can process samples for testing, access more equipment for working towards vaccines, and produce them faster.

Scientific data and knowledge are at the heart of most of the more complex challenges people and institutions face in the 21st century. OSH is a young but growing movement that has the potential to transform the current way in which scientific knowledge and equipment are produced. The course OSH takes towards influencing the current way of doing science depends on many factors within the sociotechnical system: activists’ strategies, context tensions, emergence of policy supporting OSH and new business models based on openness, the ability of institutions to adapt, cultural shifts in academic practice, public perception. The proposal of imagining possible near futures for OSH taking into account historic lessons is intended to promote reflection on strategies to foster change at these different levels, taking into account the new political

configurations that will necessarily emerge in these new scenarios.

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APPENDIX

Questions for interviewees (C: context, F: framings, Sp: Spaces, St: Strategies)

1. How would you define the GOSH community? (F)
2. Which is your role in the GOSH community? (F)
3. Which was your initial motivation for participating in it? (F)
4. Were you part of similar initiatives before joining GOSH? Which ones? (F)
5. Which initiatives inspire you or you look up to? (F)
6. How did you continue participating in GOSH since joining? (F)
7. Which are the values behind GOSH that you consider important? (F)
8. Which do you consider are highlights or milestones for the Open Hardware community in general and the GOSH community in particular? (C)
9. Who do you consider key people in the community and why? (F)
10. How has the GOSH community changed since its inception? (F)
11. Where do you see GOSH in the next few years? (F)
12. Which other institutions, networks or communities do you belong to, besides GOSH? (Sp)
13. Have you participated in new projects due to GOSH activities/connections? (Sp)
14. How do you communicate GOSH-related activities to non-GOSH people? (Sp)
15. How are tasks and work organised and distributed in GOSH? (St)
16. How do you support your work in the community? (St)
17. Which are the resources supporting GOSH? (St)
18. Which are the long-term strategies to sustain GOSH? (St)
19. Which are the mechanisms for participation? (St)
20. How does GOSH work towards achieving diversity of participants? (St)
21. Which are in your opinion the positive and negative aspects of GOSH diversity-based strategy? (St)
22. What kind of knowledge does anyone need to be part of GOSH? (St)

23. Are there any education/training instances within the community? (St)
24. What do you consider to be your greatest learning, if any, from participating in GOSH? (F)
25. Which is the impact you consider GOSH has outside the community? (F)