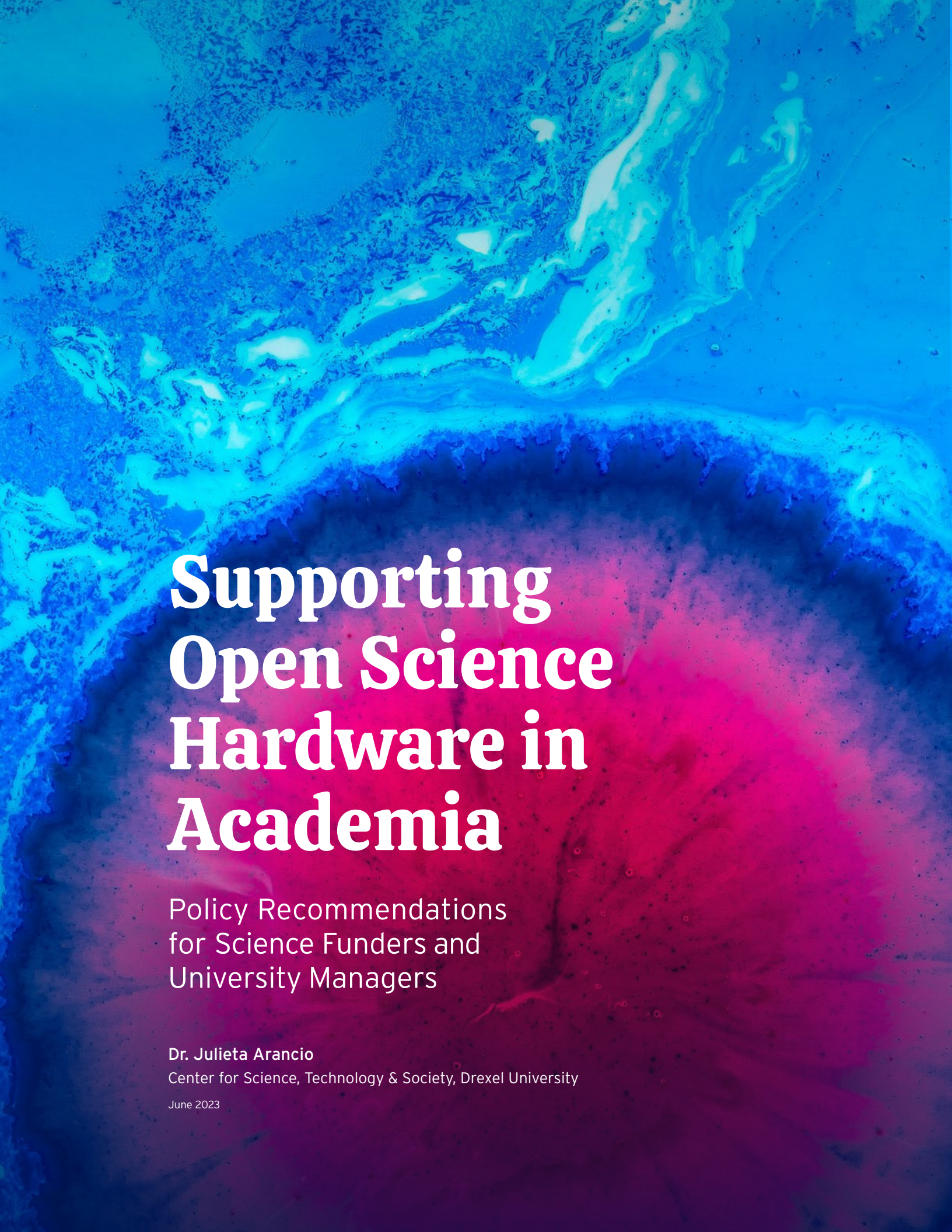

Supporting Open Science Hardware in Academia

Policy Recommendations for Science Funders and University Managers

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OVERVIEW

This report explains how research institutions and science funders can better promote open science hardware.

Why do we need open science hardware today?

Open science is becoming the new paradigm for science, technology and innovation worldwide (NASE 2018; EU). It encompasses both well-established practices, like open access to data and publications, and more recent ones like open source hardware (UNESCO, 2021).

"Open source hardware" or OSH refers to the practice of sharing design specifications of a physical object that are licenced in a way that they can be studied, modified, created, and distributed by anyone.

OSH aims to fully open the research process, aiming upstream at scientific instruments. Today the designs of science hardware are proprietary, not accessible to users. Scientists need this knowledge to make experiments fully reproducible, adaptable to new scenarios, or collect data more efficiently. They need to know how their everyday tools actually work.

In the last five years OSH has flourished in academia, with designs found in almost every discipline. The community has developed their own licenses, standards and certification programs. **Academics play a prominent role in the creation, modification and adoption of OSH designs; however, these activities remain largely invisible to research institutions.**

This report provides research institutions and funders with directions for implementing strategies to support OSH: legitimize OSH as open science, recognize OSH work and provide incentives towards professionalization. It is based on the findings of a multi-stakeholder survey run in 2022. We expect results to be particularly useful for designing roadmaps at emergent Open Source Program Offices and other initiatives aiming to institutionalize open science.

SUMMARY

This brief contains policy recommendations for funders and research institutions to promote Open Source Hardware. It is organized in the following sections:

1 ## Open Science Hardware in Academia: the Big Picture

Researchers today are both developers and users of OSH. Their work is essential for users inside and outside academia, but they get no institutional support. Tech transfer offices are a natural contact point, but their IP-focused work pushes OSH out of their scope. Most OSH developers are early career researchers who find it impossible to make their work visible for promotion; there is a real risk of losing key personnel.

2 ## Recommendations for Supporting Open Science Hardware

Open science hardware in academia needs institutional support. Similar to open science, this requires a long-term strategy; however, institutions can start taking action now.

2A ### What Institutions Can Do Today: Legitimize & Nurture

Institutions can immediately support OSH by incorporating it as a core component of open science strategies, by building institutional capabilities at TTOs or OSPOs for supporting practitioners, and by raising awareness through students' and researchers training to incentivize OSH demand.

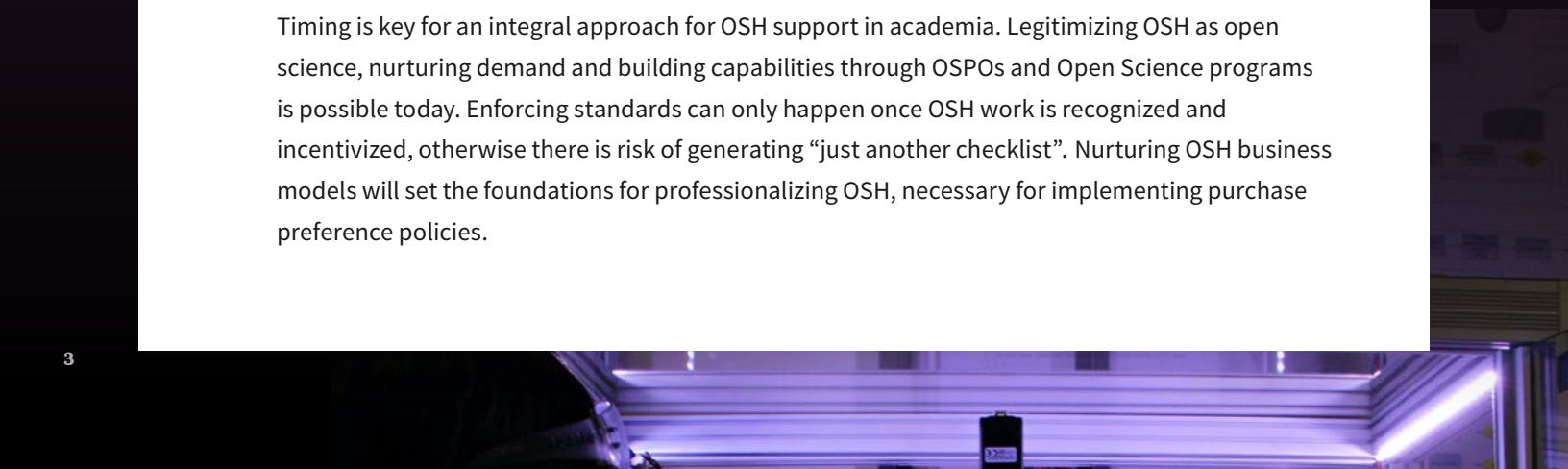
2B ### What Institutions Should Do Next: Standardize & Recognize

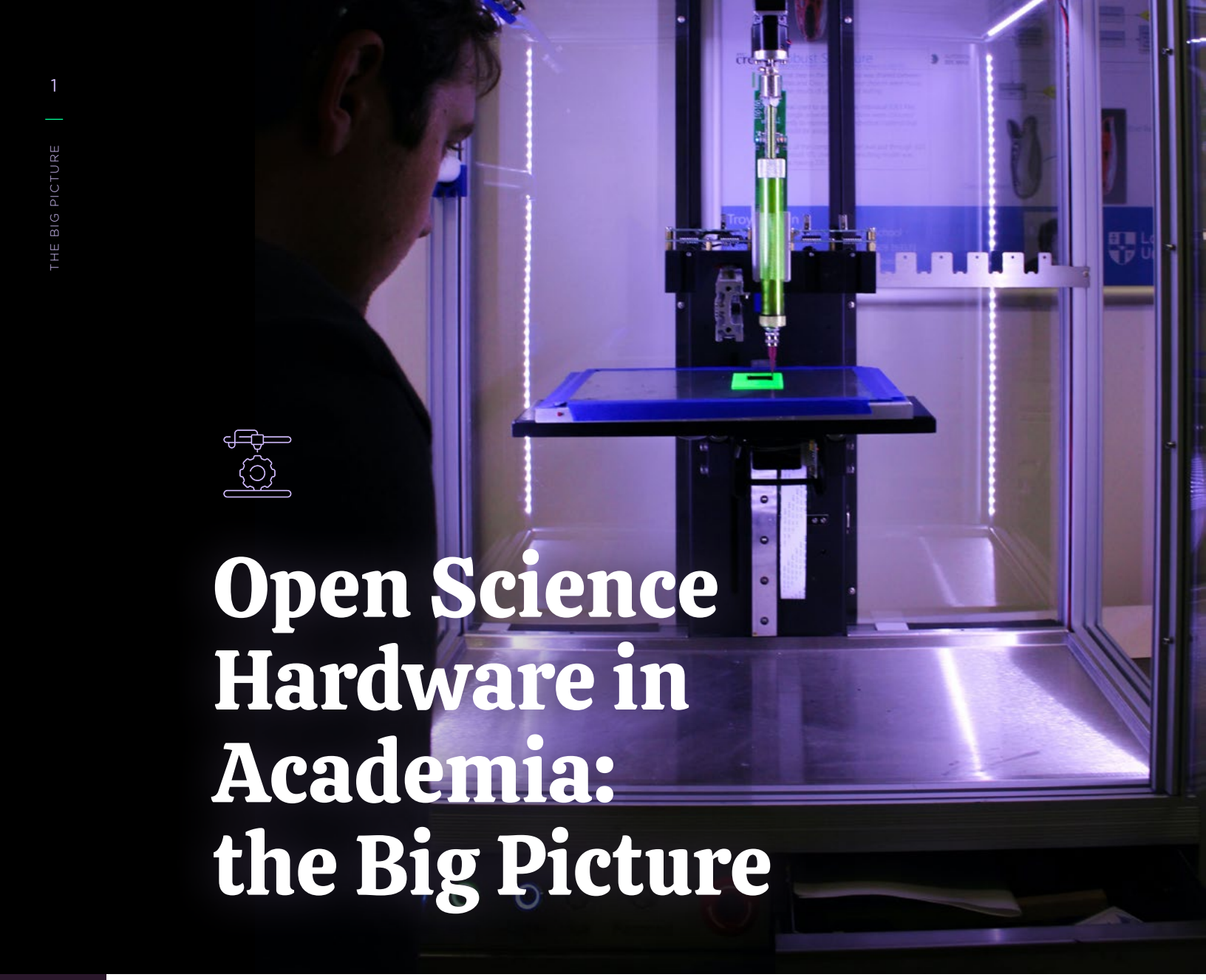
A necessary follow up for an OSH strategy includes enforcing documentation standards for OSH, creating Research Hardware Engineer roles for OSH developers, and including OSH as a pathway in entrepreneurship training and business incubators.

2C ### What Institutions Can Do in the Long Term: Assess & Reinforce

A long-term vision for establishing OSH demands developing criteria for assessing its broader social impact and incentivizing professionalization through minimal OSH preference in purchase policies.

Timing is key for an integral approach for OSH support in academia. Legitimizing OSH as open science, nurturing demand and building capabilities through OSPOs and Open Science programs is possible today. Enforcing standards can only happen once OSH work is recognized and incentivized, otherwise there is risk of generating "just another checklist". Nurturing OSH business models will set the foundations for professionalizing OSH, necessary for implementing purchase preference policies.





Open Science Hardware in Academia: the Big Picture

Researchers are everyday users of science hardware and consumables. They learn which devices to use and how to use them as part of doing lab work and belonging to research groups. Today, these scientific instruments are mostly proprietary; their design specifications are not accessible to their users.

Scientists need this information to adapt experimental settings to new questions or modify them to make data collection more efficient. To cover these needs, some researchers prototype open designs using accessible platforms and electronic components. They share these designs online through many platforms.

OSH researchers are often both users and developers of scientific instruments. Most designs today demand users to assemble the hardware themselves. Good designs are reused and adapted by fellow academics, who may contribute their own adaptations. At this point, tech support and community management can demand significant time from researchers and labs, who become project maintainers.

FIGURE 1

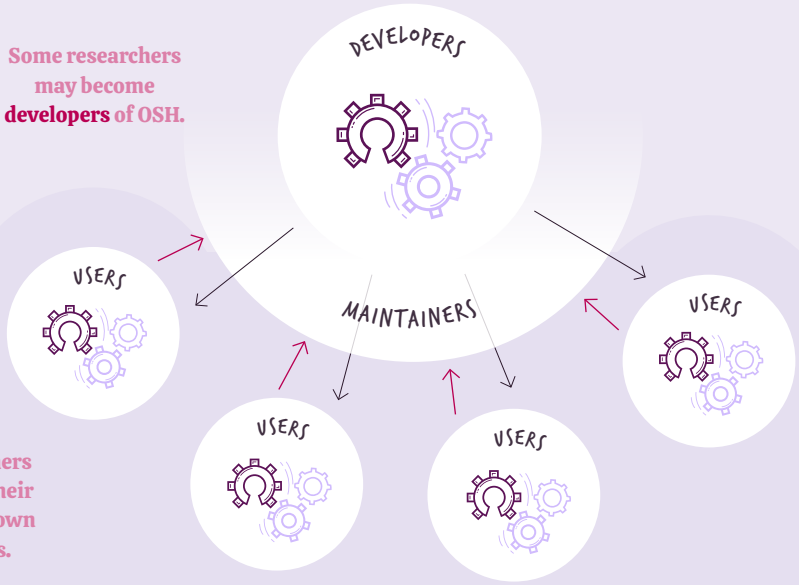
Scientific Instruments in Academia

& the **Roles** of Researchers in Open Science Hardware

	TRADITIONAL HARDWARE	OPEN SCIENCE HARDWARE
INSTRUMENTS	standard, proprietary	customizable, open source
ACCESS	limited, expensive, bureaucratic	open, affordable, distributed
METHOD	defined by design	defined by users

Experimental researchers are **users** of scientific hardware.

Some researchers may become **developers** of OSH.



When projects grow, researchers may become **maintainers** of their OSH project, dedicating their own time supporting other users.

OSH Institutional Landscape

Researchers in need of customized solutions actively search for OSH designs online and evaluate how appropriate they are for their own research. Designs can be found in peer-reviewed publications or various hosting platforms.

There are currently no procurement incentives for purchasing OSH at research institutions. When available, researchers may acquire these devices as kits or in a few cases buy them as off-the-shelf products from OSH companies. OSH devices often have a lower price tag than proprietary hardware, with companies monetizing consultancy or tech support services.

In successful OSH projects, developers interact with communities of users, inside and outside academia. At their host institutions, researchers may also interact with offices in charge of technology transfer, those assessing the impact of academic research, career performance and if available, open science programs.

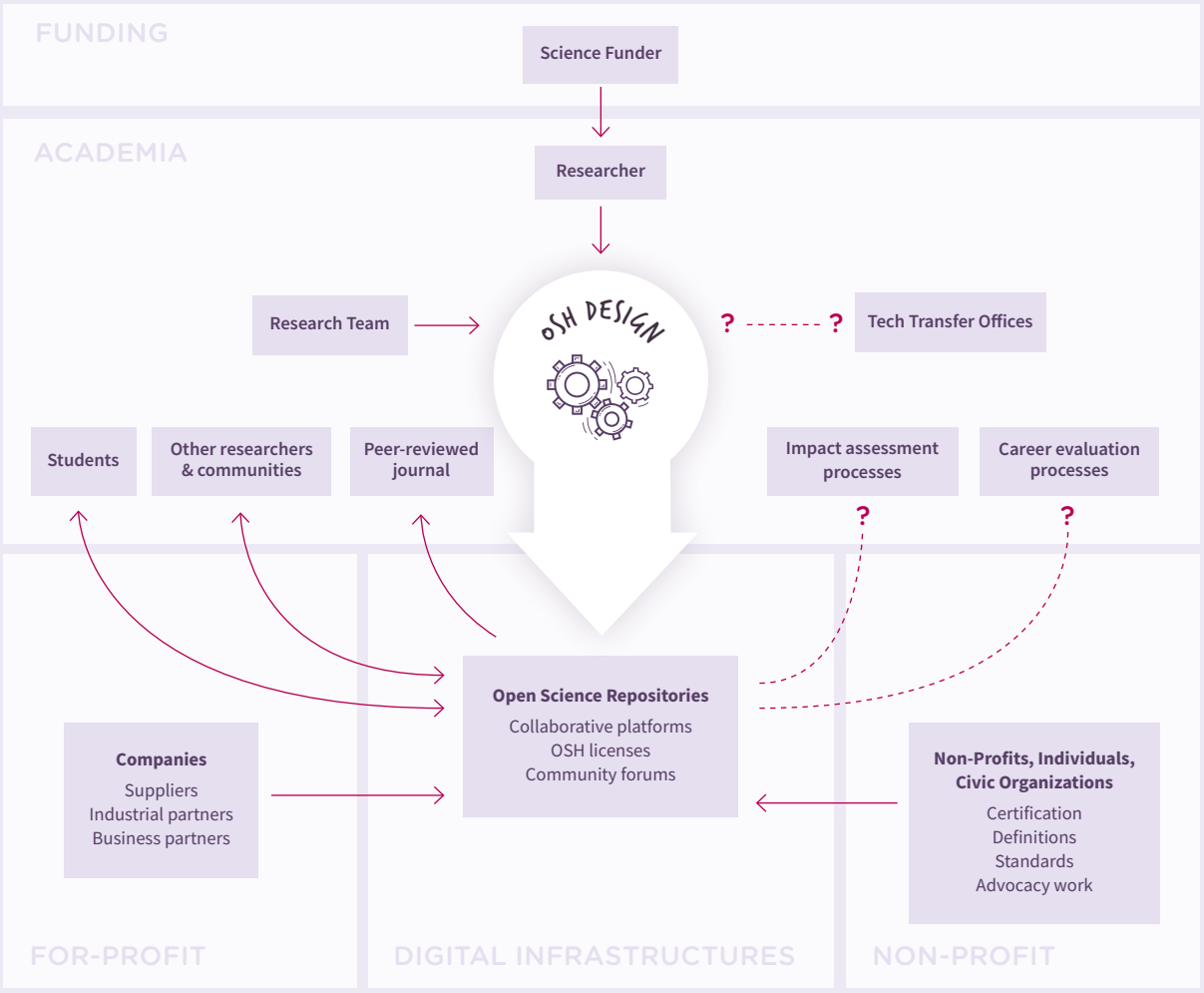
Depending on the size of the host institution and its open science strategy, institutional support varies. If the technology being developed is deemed patentable, it may generate a conflict with the tech transfer office. This is not often the case, as **patenting is expensive for universities and most of the time OSH designs are deemed non-patentable. As a result, OSH is out of scope, and researchers often get no in-house support.**

Researchers working on widely adopted projects may receive support from offices aiming to assess the impact of academic research. However, there are currently no institutionalized metrics to benchmark the impact of OSH work. Importing metrics from open source software often fails as Free Open Source Software (FOSS) has orders of magnitude more users than OSH. **Today universities have no way to track OSH developments happening at their own institutions, and researchers can't make this work count for their academic careers.**

FIGURE 2

Stakeholders In Open Science Hardware

& the **Interactions** Among Them



Recommendations for Supporting Open Science Hardware

The previous section provided an overview of the roles, interactions and conflicts in the OSH institutional landscape. Here, we describe strategies to address these problems now, in the near future and in the long term.

A **What Institutions Can Do Today: Legitimize & Nurture**

FUNDERS: Incorporate OSH into your open science incentives

RESEARCH INSTITUTIONS: Upskill your TTO or create an OSPO to provide support

UNIVERSITIES: Train students in OSH to nurture future demand

B **What Institutions Should Do Next: Standardize & Recognize**

FUNDERS: Support the development & adoption of OSH documentation standards

RESEARCH INSTITUTIONS: Create attractive career pathways for OSH developers

UNIVERSITIES: Make OSH a pathway for entrepreneurship in business incubators

C **What Institutions Can Do in the Long Term: Assess & Reinforce**

FUNDERS: Track the broader impact of OSH activities in academia

RESEARCH INSTITUTIONS: Incentivize OSH via preference in procurement policies

What Institutions Can Do Today: Legitimize & Nurture

FUNDERS:

Incorporate OSH into your open science programs and incentives.

Open science mandates in recent years legitimized and accelerated adoption of open science. Most research institutions around the world today have an open science program, an office or at least a focal point. These efforts should include OSH as part of their scope.

OSH may not apply to all research fields and situations. In certain areas pushing for OSH would be almost impossible, e.g. silicon, defense or national security work. While not feasible across the board, a few targeted programs could make a big difference to the amount of hardware being openly published, as happens with open source software.

A funders' mandate asking for OSH in sponsored research would accelerate adoption at research institutions, helping practitioners navigate roadblocks and increasing outreach dramatically. This would encourage transparency, a key for science reproducibility, and avoid waste of research funds and time.

An initial approach could experiment with OSH mandates for areas where OSH is already flourishing and accepted by part of the scientific community, such as neuroscience, microscopy, conservation ecology or environmental monitoring. One pathway is to make OSH the default if no decision is taken to make designs proprietary.

Similar to open access to publications and data, funding would be needed to support the digital infrastructures for OSH. Key decisions to make include who should own these infrastructures, maintain

them and how designs would be preserved over time. Most researchers wouldn't initially know how to share their hardware designs. Particularly in research collaborations, as OSH would imply negotiating openness between multiple stakeholders.

STARTING POINTS:

GOSH "funders salon"

A science funders discussion of how to incentivize OSH

UNESCO 2021 Open Science Recommendation

How OSH is framed and connected to the broader open science landscape

RESEARCH INSTITUTIONS:

Upskill your TTO or create an OSPO to provide support.

University leadership needs to support OSH as part of their institutional strategy. Technology Transfer Offices (TTOs) are frequently the first institutional contact point for researchers developing OSH at universities. Although their structure across institutions and geographies may vary, they are usually created within a university to manage its intellectual property (IP) assets and the transfer of knowledge and technology to industry.

The aim is to diversify technology transfer options, providing support for researchers who want to open source their designs, while letting others know that the possibility exists. This would demand generating tailored training materials and dialogs between tech transfer stakeholders and researchers. This would improve clarity on OSH licensing and other legal aspects, encouraging researchers to license more OSH, providing universities with the ability to track ongoing developments and developers with a way of making their work visible.

OSH could be better supported via emergent academic Open Source Program Offices that directly report to university leadership.

The current average size, overwork, and burden of regulatory change at TTOs may be an obstacle. Training won't be useful if TTOs perceive OSH as clashing with their current paradigm or if no concrete resources are assigned to this work. One way of addressing resistance would be to pilot a network of OSH-friendly TTOs and disseminate the experience through professional associations and open science networks.

Considering the significant mindset shift, many understand that OSH could be better supported via emergent academic Open Source Program Offices (OSPOs), or Open Science programs that directly report to university leadership. Some experts suggest this would create a more holistic approach to open source, and reduce barriers for training and adoption within institutions.

STARTING POINTS:

"Open hardware is ready to help TTOs maximize the impact of academic research"
GOSH Community strategy for turning your TTO into an OSH-friendly TTO

"Guide To Set Up A University Open Source Programs Office"
A guide by Carnegie Mellon for universities looking to implement an OSPO

"Open hardware licences – Parallels and contrasts: open science monitor case study"
A comparative study by the European Commision of open hardware licensing, risks and opportunities

UNIVERSITIES:

Train students in OSH to nurture future demand.

Including OSH content in undergraduates and graduate curricula is of high priority to achieve a critical mass of users in a near future. This recommendation is complementary to institutions addressing how to recognize OSH work, so students interested in OSH can envision future opportunities in the field.

Students in STEM and increasingly non-STEM disciplines produce prototypes as part of their learning pathway. After graduating, most students' work on prototypes is abandoned and this information is lost. Introducing students to OSH early enough and helping them in opening their designs would build skills for collaboration and increase impact of their work.

Training materials for students are already available, though there is work to do in terms of incorporating these to official curricula. A cross-cutting, interdisciplinary approach including students in STEM but also public policy, marketing/business, humanities and fine arts would be beneficial for OSH, connecting users and developers across disciplinary silos. Availability of trainers may initially pose an issue, as OSH is still a nascent community within the broader open science movement.

Embedding OSH in the curricula would also contribute to diversify the field. Similar to open source software, OSH is a currently a male-dominated field. Making it official would facilitate connection to resources and programs on Diversity & Inclusion, which are currently run at most research institutions worldwide.

STARTING POINTS:

The Turing Way: Open Source Hardware
Collaborative training material for students and researchers

Open Hardware Makers
Training materials in use at TU Berlin

Open Hardware Academy
Training materials in use at TU Delft

What Institutions Should Do Next: Standardize & Recognize

FUNDERS:

Support the development & adoption of OSH documentation standards.

OSH demands specific types of documentation. Some examples include bills of materials, assembly instructions, and specific source files in editable formats. Documentation is at the core of OSH practice; bad documentation discourages downstream adoption and community growth. Today the range of documentation practices spans from very complete and friendly to new users/contributors, to very minimal information.

The community has developed various documentation standards for OSH; these can be adopted by institutions aiming to standardize the practice. However, just requiring documentation could generate a negative impact if it is taken in isolation. **Enforcing documentation practices, which today are a burden for researchers, without any meaningful incentives can generate a negative "just another checklist" effect.**

Universities can support the development of FAIR[1] standards for hardware as part of OSH promotion strategies. FAIR standards for hardware, currently under development, are a useful strategy to connect OSH with broader open science efforts.

1. FAIR stands for Findability, Accessibility, Interoperability, and Reuse of digital assets. FAIR principles emphasize machine-actionability, such as the capacity of computational systems to find, access, interoperate, and reuse data with none or minimal human intervention.

It is key to find a balance between enforcing standards and adding more work to OSH developers. OSH in academia first produces prototypes; these can comply with approachable documentation guidelines. **More demanding documentation protocols should be enforced later, in a product phase.**

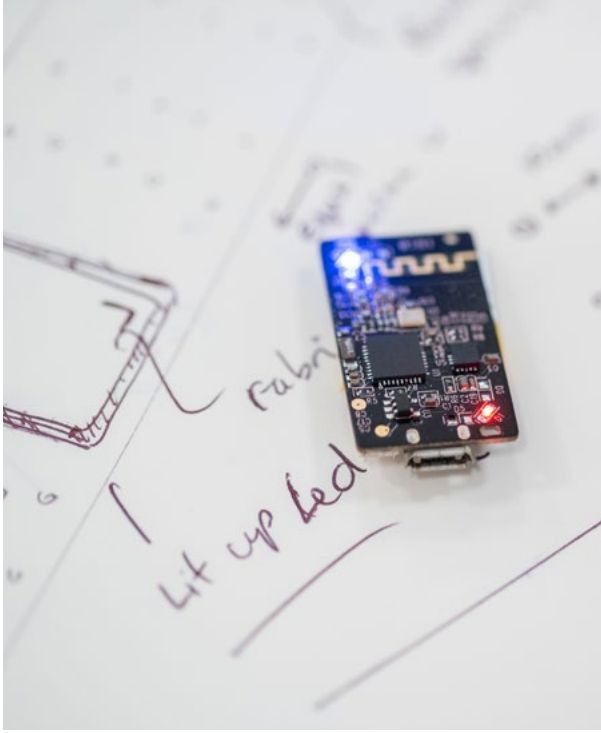
STARTING POINTS:

FAIR Principles for Research Hardware, FAIR4RH

An RDA-recognized group working on FAIR standards for OSH

Best practices - Open Source Hardware Association

Documentation guidelines to encourage the adoption of an OSH project



It is key to find a balance between enforcing standards and adding more work to OSH developers.

RESEARCH INSTITUTIONS:

Create attractive career pathways for OSH developers.

Recognizing the work of OSH developers in academia is key for sustaining efforts and reaping the benefits of open science. Today, these are “invisible” to career performance metrics, which makes the role unattractive for early career researchers.

One feasible option is to imitate the increasingly found Research Software Engineer (RSE)[2] role in academia. In a similar way, Research Hardware Engineers (RHE) could provide one-to-one assessment to researchers who are looking to customize their experimental settings, make data collection more transparent and efficient, or develop collaborations with non-academic actors supported by OSH designs.

Counting with a RHE or similar role within Open Science programs or Open Source Program Offices would accelerate the definition of performance metrics associated to OSH. It would also be instrumental for continuing OSH efforts at research institutions, preserving and sharing OSH knowledge. It is a fundamental for institutions to retain developers, and to cement the necessary cultural change towards open science.

STARTING POINTS:

TU Delft Open Hardware

Pioneer OSH institutional experience, including the creation of a Research Hardware Engineer role

Open@RIT

The Rochester Institute of Technology OSPO, which incorporates OSH

2. RSEs build software to support scientific knowledge production; they combine expertise in programming with an intricate understanding of the research process.

UNIVERSITIES:

Make OSH a pathway for entrepreneurship in business incubators.

Business models for open hardware exist but are still niche and are not included in ongoing entrepreneurship and incubator programs at universities. Universities are increasingly training students and researchers in how to commercialize their academic production, but the approach is IP-maximalist.

Researchers produce prototypes. **High quality off-the-shelf OSH products are critical for broadening adoption; these are the result of moving from prototypes to professional designs.** There is a need for more SMEs in the OSH landscape, who can provide the standardized quality control and technical support that users demand. This is an activity that goes beyond research into the business domain.

A key challenge is finding investment sources willing to accept OSH instead of proprietary licensing.

Incorporating OSH as part of ongoing commercialization training for researchers would contribute to sustainability of the practice. A key challenge is finding investment sources willing to accept OSH instead of proprietary licensing. Including OSH as part of incubators' programs would be a strong signal, to both students and industry.

Universities can start by creating Special Interest Groups, following the experience of social enterprises. This would allow institutions and advocates to explore and raise awareness of OSH amongst business stakeholders.

STARTING POINTS:

Emerging Business Models for Open Source Hardware

Collection of examples of OSH business models

DIN Spec 3105-1:2020-07

Standard for documenting OSH products

What Institutions Can Do In The Long Term: Assess & Reinforce

FUNDERS:

Track the broader impact of OSH activities in academia.

Assessing impact is key for broadening the reach and adoption of OSH projects, speaking to institutions in a language familiar to them. It is tough a time-consuming task that can often take place after projects have been running for a significant amount of time. Science funders should support on-going monitoring of OSH projects, so impact assessment can take place in the longer term.

One problem that emerges is who owns the task of assessing OSH impact. In the UK, experts suggested this activity could be included in the impact component of the Research Excellence Framework. Otherwise, this task would be part of science funders' mandates, reported as part of an OSPO activity.

Impact is often assessed using case studies of successful projects, which today are not necessarily easy to find. There is a risk of OSH case studies being compared with open source software, which often has greater adoption and number of users.

It is necessary to connect OSH activities with broader impact associated to hardware and the circular economy, including the sustainability benefits of increased repairing activities and avoided obsolescence. A potential impact to assess in the long term includes job creation through local OSH vendors and shorter supply chains. Assessing long term impact demands understand which expectations can be set for OSH

as a field. Funders should support discussions between OSH stakeholders such as developers, users, manufacturers, NGOs, OSPOs, towards building an feasible and accurate impact assessment strategy.

STARTING POINTS:

Building Blocks for Better Science, Wilson Center
Case Studies in low-cost and open tools for science

Open Flexure community stories
Short stories showing various research projects enabled by the Open Flexure microscope around the world

RESEARCH INSTITUTIONS:

Incentivize OSH via preference in procurement policies.

Making OSH a criterion for equipment purchasing would be a big step towards more cooperative, globally connected open science designs. It would contribute to reduce vendor lock-ins with suppliers of scientific instruments, increasing research resilience.

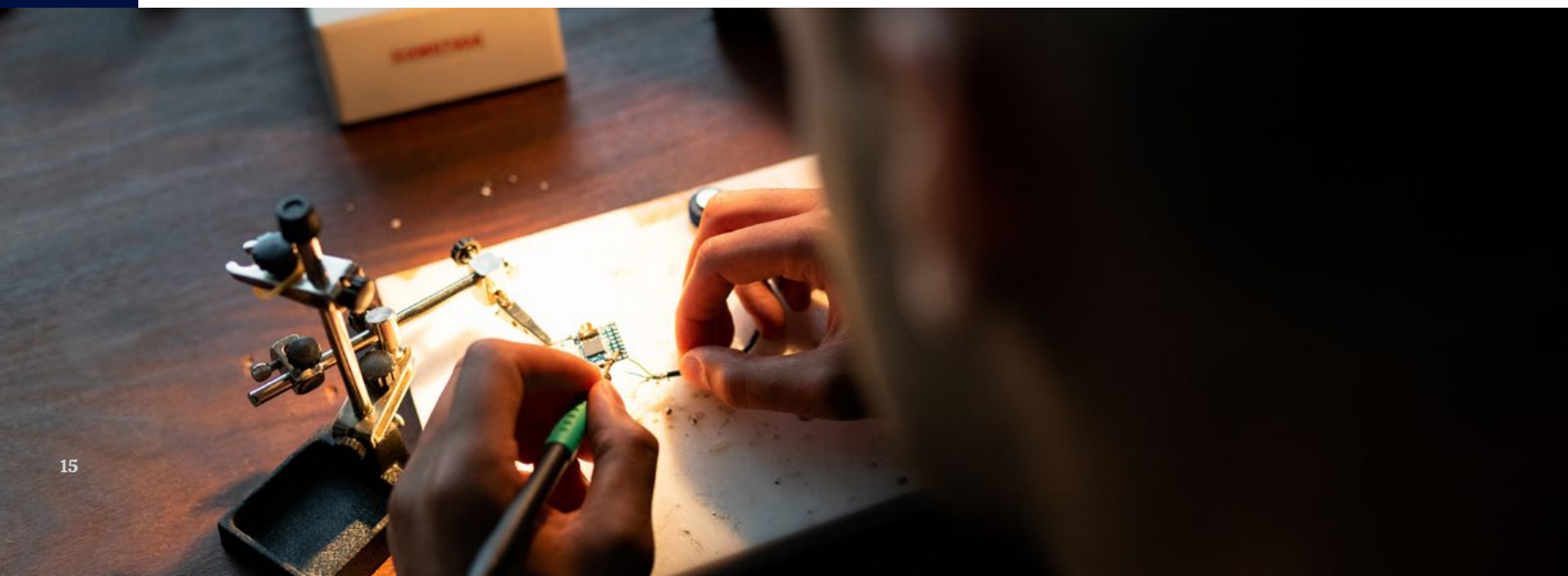
This is a long-term recommendation because the business ecosystem still needs to develop further and user capabilities need to be nurtured. There is much work to do in terms of quality standards, business creation and raising awareness before this could be implemented without generating a strong pushback.

Software-related policy offers precedents, particularly in FOSS used at public institutions. Most experts agree **it would be beneficial to have a small preference factor in purchase policies instead of a mandatory requirement**. Strong mandates risk creating incentives to "game the system" and meet the requirement, e.g. by making new open products instead of contributing to existent ones valued by the community.

STARTING POINTS:

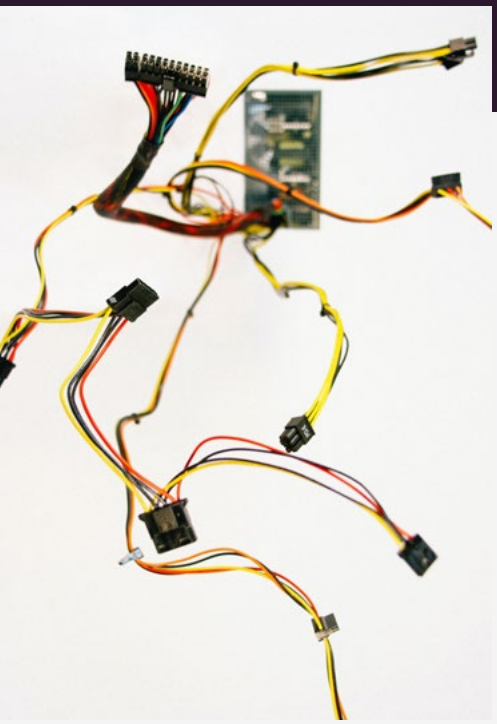
Towards national policy for open source hardware research: The case of Finland
Analysis of the strategic national benefit of implementing OSH

European Commission, Open Source Software Strategy
For reference of FOSS recognition in procurement policies



CONCLUSIONS

Timing is critical for success. Enforcing standards without building capabilities or recognizing work will generate resistance.



This report proposes first to tackle the most relevant problem: legitimize ongoing activities and build in-house capabilities to support them, so academia doesn't lose a significant number of OSH professionals in the near future. In the meantime, institutions can define formal roles for academic OSH developers, while nurturing professionalization through business incubators. At this point, standards can be enforced to support OSH best practices, and track the broader impact of OSH activities.

With institutional support, OSH can make science more efficient, accessible, and fair. Connecting to the ongoing momentum of open science policies is a great opportunity for it. As different regions and institutions have diverse approaches to intellectual property and open science, the degree of expected resistance may vary. An effective approach to promote OSH in academia should strategically plan the steps to facilitate adoption amidst multiple and sometimes opposed interests.

Research institutions can use these ideas as an opportunity to pioneer OSH, supporting their researchers while increasing outreach and access to funding. Science funders have the key responsibility of driving this change, by providing the necessary resources to make science more open, efficient, accessible and equitable for all.

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APPENDIX

Where do the recommendations come from?

Motivations

This brief closes two years of ethnographic post-doctoral work with representatives of the academic open science hardware community. As part of it and my previous doctoral work with the Gathering for Open Science Hardware (GOSH), I got involved in facilitating various discussions linking policy and OSH.

“How can policy support OSH work?” is a question that I’ve seen emerge in every community gathering. These include online webinars and sessions but also in-person unconference sessions and workshops. In particular I have worked with the open hardware for microscopy community and participated in discussions on open hardware for open environmental data, while supporting more generic OSH efforts with the GOSH community.

I have been lucky to witness how people and institutions working in other open science domains are increasingly paying attention to OSH. The inclusion of OSH in the 2021 UNESCO recommendation is an important milestone for this community. At the same time, I and others interpreted it as a clear sign that work on policy is urgent. Academia is the domain where OSH is moving fastest, and it would be a pity for the community to have an opportunity to propose a program, but have no consolidated plan.

Therefore, my postdoctoral work with Dr. Ottinger, supported by the Alfred P. Sloan Foundation, included a Policy Delphi exercise with representatives of the academic community. There is emergent policy work on OSH and of course there are many opinions, so it is necessary to understand where those align and where there is no consensus. It is my expectation that widely accepted recommendations will be strongly advocated for, while those areas without consensus spark future discussions.

Real-time Delphi Survey

To complement my ethnographic research and participantion in the GOSH community I conducted a real-time Delphi (RTD) survey during November and December 2022. I wanted to find out what policies academics thought were important, and why; aiming to set the basis for future open hardware programs.

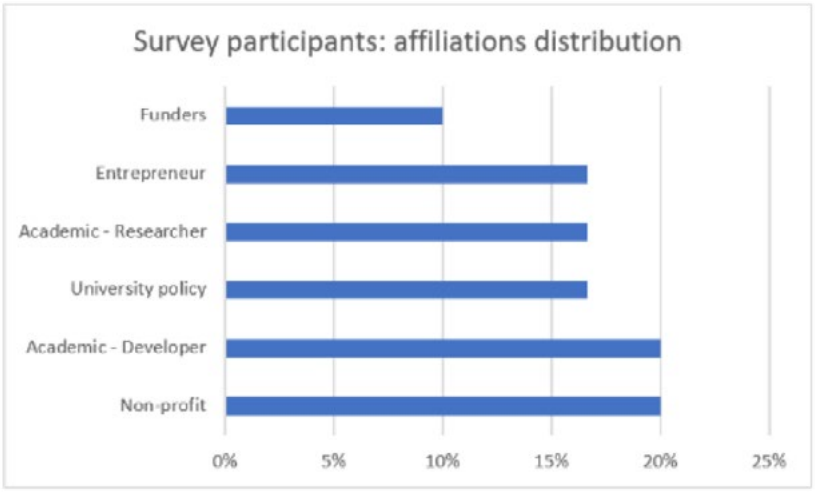
I chose a method designed to identify areas of consensus as well as disagreement. I think in these early stages showcasing the diversity of ideas in the field, instead of closing down pathways, is of utmost importance. The survey included insights from thirty subject matter experts including academic researchers, open science hardware developers and entrepreneurs, members of non-profits, academic administrators and science funders.

RTD exercises follow the principles of Delphi surveys; in this case in particular, Policy Delphi surveys. These are data collection strategies designed to generate the strongest possible opposing viewpoints on a policy issue from an experts’ panel. A typical Delphi exercise asks experts to anonymously access predefined statements, often combining quantitative rankings with open-ended questions to capture nuance. The aggregated group opinion is fed back to participants across multiple discussion rounds of the same set of theses. After each round, experts can review the aggregated results and reconsider their assessment based on the new information from the group. This structured group communication process is supposed to lead to a convergence – or divergence – of opinions, producing more accurate results than traditional opinion-polling techniques. Anonymity is key as it evens the ground of discussion, avoiding the dominance of louder voices.

The recommendations in this brief largely reflect the consensus of expert participants in the Delphi survey. Where there was significant dissent, I have tried to indicate that. I have also taken a stand based on my own observations and involvement in the community; the recommendations here are ultimately my own. The anonymized results of the survey are available online for those interested in the full picture of expert consensus and dissent.

About the exercise

The exercise was designed following the six-steps process proposed by Belton and collaborators[3] to conduct a well-founded and defensible Delphi survey. The goal of the Delphi was to identify consensus and dissent on policy recommendations for promoting open science hardware in academia. Experts were selected aiming to achieve diverse representation of backgrounds, gender and countries; they could also nominate people to participate. Out of 42 invited experts, thirty completed the survey; experts were offered financial compensation for the time dedicated to the exercise.



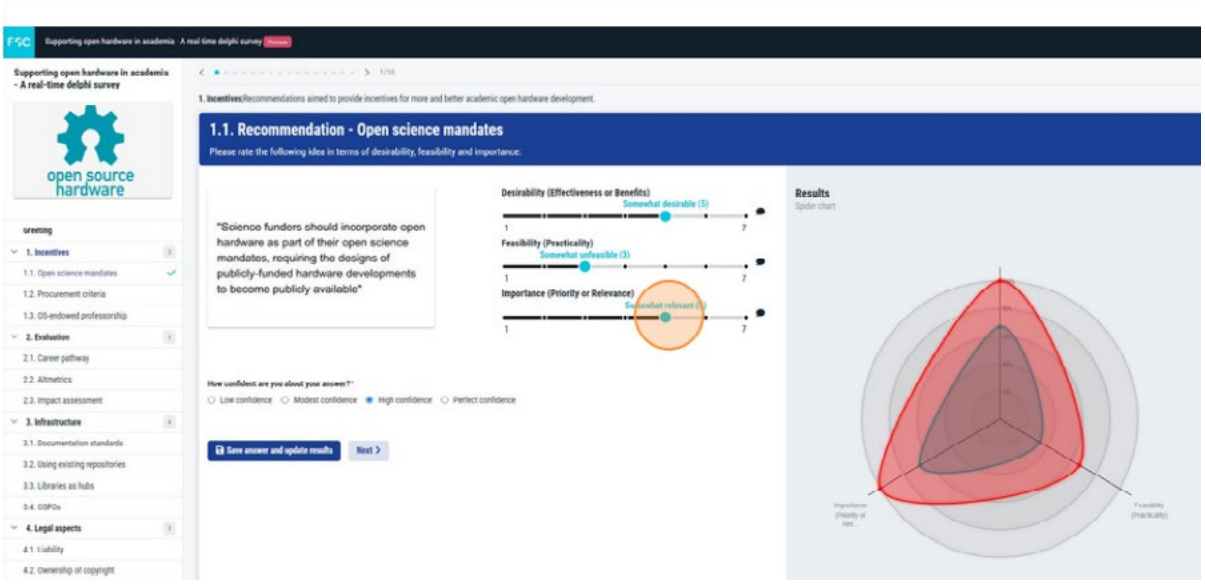
Distribution of participants' affiliation in the Delphi survey

Participants were asked to rate a series of policy recommendations in terms of desirability, feasibility and importance using a combination of a 7-point Likert scale plus qualitative notes. They were also asked to rate their confidence in their answers for each recommendation.

The statements were obtained from previous interviews I conducted with key open hardware stakeholders in academia, plus insights from available academic and grey literature. These recommendations were grouped into five categories: incentives, evaluation, infrastructure, legal aspect, capabilities. After running a pilot with a small group of colleagues, participants were asked to assess a total of sixteen statements, which on average took them 40' to complete. The full list of statements and anonymous data can be accessed in the raw data.

The choice of doing a real-time exercise responds to the geographical dispersion of participants and the cost and time-demand advantages. Real-time Delphi (RTD) surveys have emerged with the wider adoption of digital technologies and are increasingly used in various fields. RTDs do not have explicit "rounds"; as they are performed online, when participants assess a statement, they are immediately confronted with the aggregated results of all other experts' estimations who have participated thus far. Asynchronous answering means that one person can take part several times and change his or her answers until the end of the study.

3. Belton, I., MacDonald, A., Wright, G., & Hamlin, I. (2019). Improving the practical application of the Delphi method in group-based judgment: A six-step prescription for a well-founded and defensible process. Technological Forecasting and Social Change, 147, 72-82.



Screenshot of the survey platform used by participants, developed by 4Strat

The RTD platform used in this study was developed and supported by 4strat, a German consultancy firm offering expert- and data-driven Strategy Foresight Tools and Services. It allows full customization of the Delphi parameters and lets the researcher create a user-friendly interface for participants. All invited experts received a link to the survey which guaranteed anonymous access, plus a step-by-step tutorial on how to use the platform. After two months, the survey was closed and results were exported for analysis using descriptive statistics, contextualised with the qualitative data from participants' notes.

All anonymized data for this survey can be found at https://doi.org/10.5281/zenodo.8030029.