Advancing Open Science Hardware:

Opportunities and Challenges in US Government Procurement

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Executive Summary

This report delves into government procurement for Open Science Hardware (OScH) solutions in the United States. OScH refers to scientific instruments, tools, and devices that are openly designed, developed, and shared, allowing anyone to use, modify, and distribute them. This approach aims to democratize access to scientific tools and foster a collaborative environment for rapid innovation.

The report examines the current state of government procurement for OScH. It identifies the experiences, opportunities, and challenges faced by stakeholders, including researchers, advocates, business owners, entrepreneurs, and government representatives. Through insights from over 20 semi-structured interviews, the report highlights best practices, proposes actionable recommendations, and explores strategies for enhancing government procurement's effectiveness and impact in promoting OScH.

The report reveals that, while there is growing awareness of the benefits of OScH, significant challenges remain. These challenges include a lack of understanding of OScH within government agencies, misconceptions about open source solutions, rigid procurement processes, and the influence of incumbent providers. On the other hand, opportunities exist in leveraging public procurement to stimulate demand, support small and innovative businesses, promote collaboration, enhance transparency and reproducibility in research, and drive policy and cultural change.

A case study on the European Organization for Nuclear Research (CERN)'s procurement process for OScH illustrates successful strategies for avoiding vendor lock-in, fostering collaboration, and ensuring long-term maintainability. Based on the findings, the report presents a theoretical framework for public procurement of OScH, integrating conceptual models of public procurement innovation and the development of Open Science Hardware Businesses (OSHBs).

The report concludes with recommendations for raising awareness, building capacities, developing infrastructure, creating incentives, fostering cultural change, and launching pilot projects to demonstrate OScH's feasibility and benefits in real-world government applications. These steps aim to create a robust, inclusive, and collaborative scientific ecosystem, advancing the adoption and integration of OScH in government procurement practices.

Introduction

Open Science Hardware (OScH) refers to scientific instruments, tools, and devices that are openly designed, developed, and shared, allowing anyone to use, modify, and distribute them. Unlike proprietary hardware, which is typically restricted by patents and closed designs, OScH embraces the principles of openness and accessibility. The designs, blueprints, and documentation for these tools are made publicly available, often through online platforms, enabling researchers, educators, and innovators to reproduce, customize, and enhance the hardware without legal or financial barriers. This open approach not only democratizes access to scientific tools but also fosters a collaborative environment where improvements and innovations can be rapidly disseminated and implemented (Frangos et al., 2016).

The main characteristics of OScH include transparency, accessibility, and collaboration. Transparency is achieved through openly shared designs and methodologies, which enhance the reproducibility and reliability of scientific research. Accessibility is a crucial feature, as it ensures that researchers, especially those in resource-limited settings, can obtain and use advanced scientific tools at a fraction of the cost of proprietary alternatives. Collaboration is inherently promoted by the open nature of these tools, encouraging a diverse range of contributors to participate in the development and refinement process. This collective effort not only speeds up technological advancements but also ensures that the tools are continually improved and adapted to meet the evolving needs of the scientific community (Fernando & Kuznetsov, 2020). By breaking down barriers to innovation, OScH has the potential to accelerate scientific progress, foster inclusivity, and drive global advancements in various fields of research.

The vision of innovative government procurement is to leverage the significant purchasing power of the public sector to drive technological advancement, economic growth, and societal benefits. By prioritizing innovation in procurement practices, governments can stimulate the development of cutting-edge solutions that address critical public needs more effectively and efficiently. This approach encourages the adoption of new technologies and methodologies, fostering a competitive market where innovation thrives. Innovative government procurement aims to create a dynamic ecosystem where public investments meet immediate operational requirements and contribute to long-term strategic goals, such as sustainability, economic resilience, and improved public services.

The importance of innovative government procurement lies in its ability to catalyze change across multiple sectors by setting a precedent for private industry and encouraging the development of solutions that might not otherwise receive market attention. Governments can address complex challenges such as climate change, public health crises, and infrastructure modernization by actively seeking out and supporting innovative products and services. This proactive stance helps bridge the gap between research and market application, ensuring that innovative ideas are translated into practical solutions with tangible benefits. Moreover, by fostering a culture of innovation within government operations, public procurement can drive efficiency, reduce costs, and improve public service quality, ultimately enhancing citizens' well-being and strengthening public trust in government institutions.

The primary objective of this report is to provide a landscape of the current state of government procurement for OScH solutions in the United States, encompassing different government levels. The report aims to identify and analyze the experiences, opportunities, and challenges faced by various stakeholders, including researchers, advocates, business owners, entrepreneurs, and government representatives, in the procurement process. By synthesizing insights from a series of semi-structured interviews, this report seeks to highlight best practices, propose actionable recommendations, and explore strategies for enhancing the effectiveness and impact of government procurement in promoting OScH. Ultimately, the report aspires to inform policy development, support the adoption of innovative procurement practices, and foster an inclusive and collaborative scientific ecosystem.

Public Procurement of Innovation & the Adoption of Open Science Hardware (OScH)

What is Public Procurement of Innovation?

Public procurement has emerged as a powerful tool for stimulating innovation and driving economic growth. Governments can leverage their significant purchasing power to create markets for innovative products and services (Edler & Uyarra, 2013; Edquist, 1997). This approach, known as public procurement of innovation (PPI), has gained traction in recent years as a demand-side policy instrument (Uyarra et al., 2016). PPI can occur at different stages of market development, from initiating new markets to consolidating mature technologies (Edler et al., 2005). While the concept is not new, having been used in technology procurement projects in the mid-20th century, it has experienced a rebirth in the context of the knowledge-driven economy (Rolfstam, 2015). PPI requires greater interaction between procurers and suppliers compared to traditional procurement, as it involves transferring knowledge about needs and potential technological solutions (Edler & Georghiou, 2007). Implementing PPI effectively can contribute to technological infrastructure and foster innovation-led growth (Edquist & Zabala-Iturriagagoitia, 2015; Uyarra et al., 2016).

There is a growing awareness and effort among federal procurement managers to improve procurement processes and promote innovation (Rolfstam, 2015). Initiatives by the Biden Administration, such as those led by the White House Office of Federal Procurement Policy, aim to leverage federal purchasing power, introduce innovative practices, and enhance efficiency (Open Government Partnership, 2024); nonetheless, public procurement for innovation for OScH solutions is still far from being part of the conversation.

The relevance of government procurement innovation lies in its potential to not only meet public sector needs more effectively but also to stimulate broader economic growth and competitiveness by fostering a culture of innovation among suppliers and within the government itself. This approach can lead to more efficient use of public funds, better public services, and increased opportunities for small and innovative businesses to participate in government contracts (Mazzucato, 2021).

How does it relate to the adoption of Open Science Hardware?

OScH solutions align particularly well with the PPI vision by promoting three core aspects: democratizing access to scientific tools through the creation of open source alternatives to proprietary equipment at a fraction of the cost (Frangos et al., 2016; Moritz et al., 2019; Fernando & Kuznetsov, 2020), fostering collaborative environments where improvements and innovations can be rapidly shared and implemented (Dosemagen et al., 2017; Moritz et al., 2018), and accelerating innovation by encouraging the wider adoption of tools and the continuous evolution of designs (Frangos et al., 2016; Moritz et al., 2016; Serrano, 2016). Additionally, providing options to purchase only proprietary solutions, which have been severely criticized in the past for hindering innovation (Boldrin et al., 2011), further emphasizes the need for OScH to ensure a more open and progressive approach to scientific advancements.

OScH is also emerging as a crucial component in enhancing research capacity and addressing disparity in access to the tools of science globally. By making designs publicly available, OScH can reduce costs by up to 87% (Pearce, 2020), improve reproducibility, and enable adaptation to local needs. It supports various fields, from environmental monitoring to microscopy (Hsing & Johns, 2023). OScH democratizes research by providing access to affordable, adaptable tools for both professional and civic science settings (Keller et al., 2023). It also promotes knowledge production globally since a wider range of users, including those in resource-limited settings, can access and utilize advanced technologies that might otherwise be out of reach due to cost or proprietary restrictions. This inclusivity ensures that the benefits of innovation are more widely distributed helping achieve Sustainable Development Goals (Arancio et al., 2022).

Furthermore, the open nature of these solutions enhances the overall impact and effectiveness of public spending in research and innovation. Open architectures and standards enable governments and publicly funded endeavors to become vendor-agnostic, fostering innovation and cost-effective utility services (Fishenden & Thompson, 2013). By investing in adaptable and open technologies, the government can ensure that the innovations it funds can be continuously improved and tailored to meet evolving needs. This adaptability is often lacking in proprietary solutions, which are typically more rigid and less collaborative. This alignment and effectiveness make them a superior choice for enhancing the impact of other government investments in research and development.

In sum, the procurement of OScH solutions within government purchases can significantly advance its adoption and development in at least seven dimensions. By prioritizing OScH solutions, government procurement can **increase demand and open new market opportunities** for OSHBs. This can encourage suppliers to develop and offer OScH solutions, knowing there is a reliable market.

Public procurement can **support innovative small and medium enterprises (SMEs)** by setting aside contracts specifically for smaller companies or start-ups that develop OScH. This support can help smaller OScH developers to scale their innovations and compete with larger, established companies.

Government initiatives can **promote collaboration between various stakeholders**, including academic institutions, private companies, and public organizations. This can lead to the development of standardized OScH, making it easier to integrate and use across different research settings.

OScH inherently supports the principles of transparency and reproducibility in scientific research. By adopting and promoting OScH, government procurement policies can **enhance the integrity and reliability of publicly funded research**.

Government contracts can represent a significant revenue stream for OSHBs, providing a more sustainable income source. The financial support from these contracts can help overcome the high initial costs and risks associated with developing new and open technologies and help smaller OScH developers to **scale their innovations investments and compete with larger, established companies**.

OScH can be more affordable and accessible than proprietary alternatives. Government support for OScH can ensure that a broader range of researchers, including those in underfunded and resource-limited settings, have access to the tools they need, thereby **promoting global access to scientific research**.

Lastly, government endorsement and use of OScH can **drive a cultural shift** towards adopting open hardware solutions in the broader scientific community. It sets a precedent that can influence other funding bodies and institutions to adopt similar practices.

Public Procurement for Open Science Hardware

Governments can encourage the use of OScH in three main ways: through fiscal policy, government spending, and as purchasers. Firstly, through fiscal policy, governments can provide tax incentives to encourage companies and organizations to develop and maintain OScH. By offering tax breaks or credits, they can reduce the financial burden on these entities, making it more attractive to invest in OScH.

Secondly, as research funders, governments can support the development of OScH by creating funding programs. These programs can provide seed funding to startups or research institutions that are developing open hardware solutions. Additionally, governments can develop comprehensive open science policies that mandate OScH for all publicly funded research, requiring that such hardware be openly licensed to maximize reusability.

Lastly, as purchasers, governments can create demand for OScH by developing or updating procurement policies that prioritize the acquisition of OScH in federal agencies. This might include creating special categories or criteria for evaluating open source solutions, ensuring that open hardware is considered and prioritized in procurement decisions.This study aims to focus on the capacity of governments as buyers procuring for OScH. We explored the challenges and opportunities for the United States to integrate OScH into its procurement processes. Through rich conversations with government officers, members and researchers of the OScH community, we were able to map the existing challenges and explore potential solutions. This research allowed us to convey an informed set of steps that governments at all levels could take to procure OScH effectively. By understanding the nuances of these challenges and the innovative solutions proposed, we hope to provide a clear roadmap for enhancing the adoption and integration of OScH in government procurement practices.

Challenges for Public Procurement Innovation of Open Science Hardware Solutions

To promote OScH from government agencies, innovation is needed from both the demand side (government) and the supply side (OSHBs). Twenty two semi-structured interviews were conducted with government officials, decisionmakers, business owners, practitioners, advocates, and researchers in the OScH industry. The goal was to understand the challenges and opportunities in government procurement processes for OScH solutions and the challenges and opportunities for OSHBs to participate in public tenders successfully. The interviews were analyzed, and primary challenges were identified through thematic clustering. These challenges were ranked based on how frequently they were mentioned by the interviewees and are presented in the following sections.

Challenges for Government Agencies

One major challenge identified is the **lack of awareness** of OScH solutions. Government officials and decisionmakers often have limited knowledge of these solutions and their advantages over proprietary options, such as increased transparency, adaptability, and potential cost savings. This lack of understanding hampers the adoption of OScH in government procurement.

Another significant challenge is the **misconceptions about open source** within government institutions. Concerns about security, reliability, customer service, and post-sale support persist despite evidence showing that open source solutions can be just as secure and reliable as proprietary ones. Robust community and commercial support options are often overlooked, contributing to these misconceptions.

Inefficiencies and rigid processes in government procurement also pose substantial obstacles. The bureaucratic nature of these processes often leads to slow and resistant change, making it difficult to integrate innovative procurement models that favor open hardware solutions. This rigidity impedes the adoption of new and effective procurement practices.

The **one-size-fits-all approach to call for tenders** in government procurement further complicates the adoption of open hardware solutions. Standardized calls often fail to accommodate the unique requirements of open hardware. This institutional inertia, combined with a general risk-averse attitude, hinders the exploration and adoption of innovative procurement practices.

Advocating for open hardware is also more complex compared to software. While open software involves intangible digital products, open hardware requires physical devices, adding layers of complexity to procurement processes. This additional complexity can deter officials from pursuing open hardware solutions.

Moreover, the **procurement processes for software and hardware are inherently different**, with hardware procurement being more complicated. The physical nature of hardware introduces additional logistical and technical considerations, making it more challenging to implement open hardware solutions.

Finally, **path dependencies (Marquis & Tilcsik, 2013) and the influence of incumbent providers** create significant barriers to adopting open hardware solutions. Existing relationships and dependencies on private sector providers can stifle competition and innovation. These established providers often have substantial influence and discretionary purchasing practices that further entrench their positions in government procurement.

Challenges for Open Science Hardware Businesses (OSHBs)

Converting laboratory prototypes into commercially viable products poses a significant challenge for OSHBs. This involves meticulous operations and supply chain management, encompassing material sourcing, quality control, and the establishment of reliable manufacturing processes. Material sourcing entails identifying suppliers capable of consistently delivering high-quality raw materials at competitive prices. Quality control ensures that each product adheres to specific standards for performance, durability, and safety, which is crucial for customer satisfaction and regulatory compliance. Establishing **reliable manufacturing processes** involves designing and optimizing production lines to efficiently produce large volumes of products while upholding quality. This may involve selecting appropriate machinery, training employees, and implementing stringent inspection protocols. Overall, these steps are vital for transitioning from small-scale prototypes to increased production.

Transitioning from an academic project to a commercial entity involves **a change in mindset and mission**. Academic projects usually focus on research and innovation, aiming to explore new ideas, generate knowledge, and publish findings. In this context, success is measured by academic achievements such as publications, grants, and peer recognition. Conversely, commercial entities need to prioritize business-oriented activities such as marketing, customer support, and profitability. Marketing involves promoting products to potential customers through various channels to increase sales and brand awareness. Customer support ensures that users have a positive experience with the product, which can lead to repeat business and positive reviews. Profitability is crucial for sustaining and growing the business, requiring careful financial planning and management. The change in focus and actions may be challenging and may not be relevant in academic settings. Researchers may feel uneasy or unready to participate in business endeavors, and the emphasis on making a profit may appear distant from their missions. As a result, transitioning successfully requires not only **acquiring new skills and strategies** but also a cultural shift within the organization.

Balancing open licensing with business sustainability is a major challenge for OSHBs. Open licensing promotes collaboration and innovation by making designs freely accessible, but it can also limit revenue streams by enabling competitors to replicate and sell similar products or sell their designs to larger proprietary actors. To maintain sustainability, OSHBs must **find innovative business models** that leverage open licensing while generating income. Developing a strong financial strategy is crucial for this balance. Some OSHBs have successfully used pre-selling and crowdfunding to fund their initial phases. These methods not only provide the necessary capital but also validate market interest. However, as the business grows, more sophisticated financial planning is needed to ensure steady cash flow, manage operational costs, and invest in further development. Especially when dealing with large public institutions that often have lengthy payment cycles, financial strategies must also account for potential payment delays.

Validation and regulation are also significant hurdles, particularly for OSHBs developing medical devices or products requiring adherence to stringent standards. These standards ensure safety, efficacy, and compliance with industry regulations but often involve **lengthy and expensive testing processes**. Meeting these regulatory requirements can be resource-intensive, demanding specialized knowledge and equipment. Failure to comply can result in severe consequences, including fines, recalls, or being barred from the market.

Developing **competitive pricing strategies** is essential for OSHBs to enter and expand. Many OSHBs initially price their products below market rates to attract customers and increase accessibility. While this strategy can drive user acquisition, it must be balanced with the need **to fund expansion and innovation**. Sustainable pricing strategies should allow for investment in research and development, marketing, and scaling production. Over time, strategic adjustments in pricing can help OSHBs build a robust financial foundation while remaining competitive.

Navigating and understanding government procurement processes presents its own set of challenges. These processes are notoriously complex, with numerous steps, requirements, and legal obligations that can be daunting for OSHBs. Understanding these processes requires significant time and resources to ensure compliance with all regulations. This includes comprehending the documentation needed, the criteria for selection, and **the obligations that come with winning a bid**, such as maintaining specific standards and fulfilling extensive reporting requirements. Clarity in these areas is crucial to avoid potential legal and financial pitfalls.

Lastly, **ensuring consistent cash flow** is crucial for developing the capabilities **necessary to participate in public tenders.** OSHBs require funding to enlist legal support in order to navigate contract complexities, fulfill required guarantees for bids, and effectively manage cash flow to manufacture and distribute products prior to receiving payment. This financial stability guarantees that the business can fulfill its obligations without compromising its operations.

Case Study: CERN's Procurement Process for Open Science Hardware

CERN and federal agencies share two main parallelisms: large budgets capable of driving innovation and high-value missions. Both entities operate with substantial funding, allowing them to pursue significant research and development initiatives. CERN, funded by its member states, can undertake large-scale, high-impact projects like the Large Hadron Collider. Similarly, federal agencies such as NASA and NIH receive substantial federal funding to support their high-value projects, including space missions, advanced medical research, and large-scale scientific studies. These moonshot-like projects may require more comprehensive ways to incentivize innovation (Mazzucato, 2021). These public institutions can actively shape and create markets by investing in high-risk, high-reward projects that the private sector might avoid.

CERN has been at the forefront of open science initiatives, including developing and procuring OScH. Javier Serrano, head of the Electronics Design and Low-level software development section at CERN, provided insights into CERN's approach to open hardware procurement, its motivations, and the challenges faced along the way. While proprietary procurement still represents the majority of purchasing of hardware at CERN, this case study explores their innovative procurement process for OSH, focusing on their strategies to avoid vendor lock-in and foster collaboration with specialized companies.

In 2008, CERN began exploring open hardware to renew the control system of its accelerators. The initiative was inspired by the successful collaboration practices in open source software, particularly those seen in the Linux community. The primary goals were to avoid vendor lock-in, ensure long-term maintainability, and leverage the benefits of open collaboration.

CERN's Motivations for Open Hardware

One of the primary motivations for CERN's adoption of open hardware was to avoid vendor lock-in. CERN's hardware typically has very long life cycles, often 40-50 years, which can conflict with the commercial cycles of proprietary vendors. Proprietary hardware vendors may discontinue products or go out of business, leaving CERN without support or replacement parts for critical systems. By opening hardware designs, CERN can solicit bids from various manufacturers, ensuring greater flexibility and long-term sustainability. This approach allows CERN to avoid dependency on a single vendor, thus reducing the risks associated with vendor lock-in and ensuring that its hardware remains functional and supportable for its entire life cycle.

Enhanced collaboration was another significant motivation for CERN's adoption of open hardware. Open hardware enables collaborative development similar to open source software, allowing CERN to engage with external companies for design and support. This collaborative approach ensures that the knowledge and expertise required to maintain the hardware are not confined to one vendor. By working closely with companies that understand the domain in which the hardware will be used, CERN can leverage a broader support network. This not only improves the quality and reliability of the hardware but also allows for more innovative solutions, as multiple entities contribute their expertise and insights during the development process.

Long-term maintainability was also crucial in CERN's decision to adopt open hardware. With open designs, CERN can ensure that its hardware remains maintainable and upgradable over the decades-long life cycles required for its equipment. Open hardware designs can be freely accessed, modified, and improved by anyone, which means that CERN is not limited to the support and upgrade options provided by a single vendor. This approach mitigates the risk of obsolescence and ensures that CERN can continue to support and improve its hardware without being dependent on any single vendor's commercial interests. It also allows CERN to make necessary upgrades and modifications to the hardware as technology evolves, ensuring that its systems remain state-of-the-art and capable of meeting the demands of cutting-edge research.

CERN's Procurement Process

CERN employs a structured procurement process to source open hardware, encompassing several key steps. The process begins with the design phase, where CERN develops open hardware designs in collaboration with external companies. These designs are made publicly available, allowing any company to bid on their production. By publishing these designs, CERN ensures that there is a broad base of potential manufacturers who can participate, fostering competition and innovation.

The next step is the call for tender[1], a standard mechanism at CERN used to invite companies to manufacture and sell the open hardware designs. This process is transparent and competitive, ensuring fair access for all interested parties. By clearly defining the requirements and expectations in the tender documents, CERN can attract bids from a diverse range of companies, further enhancing the competitive nature of the procurement process.

When it comes to selecting companies, CERN has specific criteria. They prefer to work with companies that not only manufacture hardware but also have a deep understanding of the domain in which the hardware will be used. Companies are selected based on their ability to provide ongoing support and their expertise in the relevant field. This ensures that the companies can offer robust and knowledgeable support for the hardware, which is crucial for maintaining high standards and addressing any issues that may arise during the hardware's lifecycle.

The selected companies often collaborate with CERN during the design phase, ensuring that the hardware meets specific requirements. This partnership is facilitated by the open nature of the designs, which eliminates the risk of vendor lock-in. By working closely with these companies from the early stages of design, CERN can ensure that the hardware is tailored to its needs and that any potential issues are addressed before the production phase. This collaborative approach not only improves the quality of the hardware but also strengthens the relationship between CERN and its suppliers, fostering a more innovative and supportive environment for developing advanced scientific equipment.

Challenges and Solutions

One of the significant challenges CERN faced was the scalability of support for widely adopted designs. When open hardware designs become successful, they generate numerous questions and support requests. To address this, CERN works with companies that have a deep understanding of the hardware and can provide robust support to users. These companies are expected to understand the domain thoroughly, allowing them to handle support queries effectively. This partnership ensures that the original designers at CERN can focus on new developments rather than spending excessive time on support, thereby fostering an environment of continuous innovation.

To manage this support demand, CERN strategically collaborates with companies capable of offering comprehensive support services. These companies often specialize in the same domain as the hardware being produced, enabling them to provide high-quality, knowledgeable assistance to users. This approach not only helps in managing the support load but also ensures that users receive accurate and reliable help, maintaining the overall quality and reliability of CERN's open hardware projects.

CERN also had to navigate the challenge of incentivizing companies to participate in open hardware projects.CERN has the leverage to create substantial and long-lasting business opportunities, particularly for providers in niche markets, making it a significant and influential client. A call for tender from CERN for procuring open science hardware (OScH) solutions plays a crucial role, as it provides a clear financial incentive for companies to engage. Companies can implicitly consider the return on investment when developing OScH solutions, including those that might not have considered open hardware otherwise. Understanding and aligning with CERN's needs and work culture gives providers a significant competitive advantage, making the financial benefits and return on investment more apparent through successful collaboration. These tenders outline the potential business opportunities, encouraging companies to invest time and resources into OScH projects.

Additionally, CERN emphasizes the long-term benefits of open hardware, such as avoiding vendor lock-in and ensuring long-term maintainability, which resonate with companies' strategic interests. Companies are made aware of the sustainable business model that open hardware can provide, including the possibility of future contracts and collaborations. This strategic emphasis on the long-term advantages helps in aligning the interests of the companies with the goals of CERN, creating a mutually beneficial partnership.

Furthermore, CERN's procurement strategy involves working closely with companies during the initial design phase. This collaboration allows companies to understand the project deeply and see the potential for future opportunities. By being involved from the beginning, companies are more likely to feel invested in the success of the project, increasing their commitment to providing high-quality support and ensuring the hardware's success.

Conceptual Model for Open Science Hardware Procurement

CERN's approach to open hardware procurement is possible due to six unique factors. On the demand side, three key elements stand out. First, the mission-oriented and technically enabled decisionmakers at CERN play a crucial role. For CERN's researchers, it is clear how OScH solutions align with CERN's knowledge transfer mission. Researchers who leverage the demand are also knowledgeable about the products that they are soliciting, allowing them to engage with vendors more effectively to meet the researcher's needs.

Second, CERN has developed significant institutional knowledge and actionable evidence regarding the innovation of its procurement processes. This institutional know-how has been co-created through partnerships with researchers, vendors, and staff members. By involving all relevant stakeholders, CERN has crafted more fluid procurement practices that better serve its mission and continuously adapt to evolving needs and challenges. This collaborative approach ensures that the procurement practices remain relevant and practical.

Third, taking a collaborative and informed approach has led to the development of adaptable and well-optimized procurement mechanisms. These mechanisms enable CERN to acquire solutions precisely tailored to its mission requirements. Furthermore, this adaptability ensures that knowledge-sharing and innovation remain active within the organization.

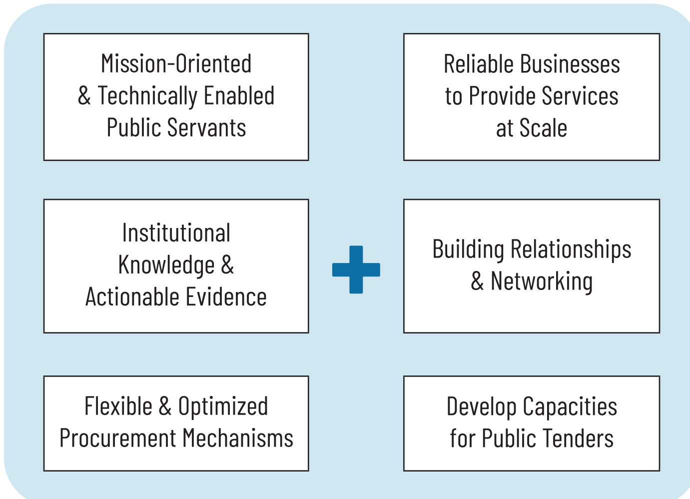
On the supply side, three additional elements contribute to the success of CERN's open hardware procurement model. Reliable businesses capable of providing services at scale are essential. Vendors collaborating with CERN are often established (not necessarily large) and trustworthy companies with the capacity to deliver high-quality services on a large scale. These companies bring stability and dependability to the procurement process, ensuring that the hardware produced meets CERN's stringent standards and can be reliably supported over its long lifecycle.

Building relationships and networking are also critical components. CERN researchers and staff have developed strong relationships with vendors, leading to fruitful collaborations in critical areas such as tender development and problem-solving. While formal contracts govern all interactions, these relationships often operate in a context of mutual trust and commitment to CERN's mission. This trust-based collaboration enhances the effectiveness and efficiency of the procurement process.

Finally, developing capacities for tenders has been a significant factor. Vendors have gained a deeper understanding of CERN's unique needs, requirements, and operational nuances through their ongoing collaborations with CERN. This knowledge positions them advantageously when competing for tenders. By understanding the intricacies of CERN's operations, these vendors can tailor their bids more effectively, increasing their chances of success and ensuring that the hardware solutions they provide are perfectly aligned with CERN's expectations.

Based on these unique characteristics observed, a conceptual model for Open Science Hardware Procurement has been created, shown below.

Figure 1: Procurement for Open Science Hardware Model



Source: Author's elaboration based on interview findings.

Through these practices, CERN not only enhances the quality and reliability of its hardware but also fosters a more open and collaborative scientific community. By demonstrating the feasibility and benefits of open hardware procurement, CERN sets a precedent for other research institutions, encouraging them to adopt similar practices. This case study highlights the potential for innovative procurement strategies to drive scientific progress and build a more resilient, interconnected research ecosystem.

Public Procurement for Open Science Hardware Framework

To better understand the conditions under which public procurement for open science can happen, the **Public Procurement for Open Science Hardware Framework** was developed during this study. This theoretical framework is based on literature and interview analysis and presents three conceptual models. It aims to explain the necessary conditions within government agencies (demand side) and the conditions required in OSHBs (supply side) to make public procurement for OScH possible.

The framework integrates two key models:

1. **Public Procurement Innovation Model**
2. **Open Science Hardware Government Contracting Model**

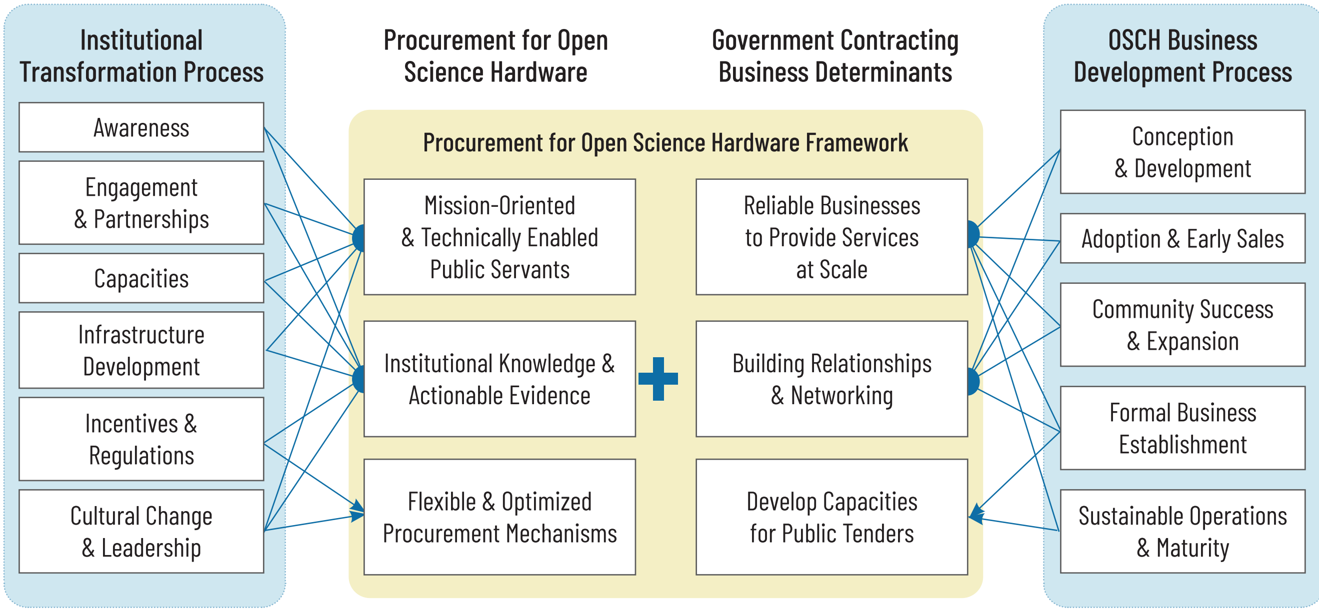
Each model comprises a process and a series of outcomes:

- **Public Procurement Innovation Model**:
  - **Process**: Institutional Transformation Process
  - **Outcomes**: Procurement Innovation Determinants

- **Open Science Hardware Government Contracting Model**:
  - **Process**: Open Science Hardware Businesses Development Process
  - **Outcomes**: Government Contracting Business Determinants

These determinants are the outcomes of the processes involved and act as variables in the **Procurement for Open Science Hardware Model**, which was developed in the CERN case study. The arrows depict the relationships between each concept and how they contribute to the variables in the **Procurement for Open Science Hardware Framework**. The complete framework is presented below, and the associated models and their components are further detailed in the document.

Figure 2: Procurement for Open Science Hardware Framework

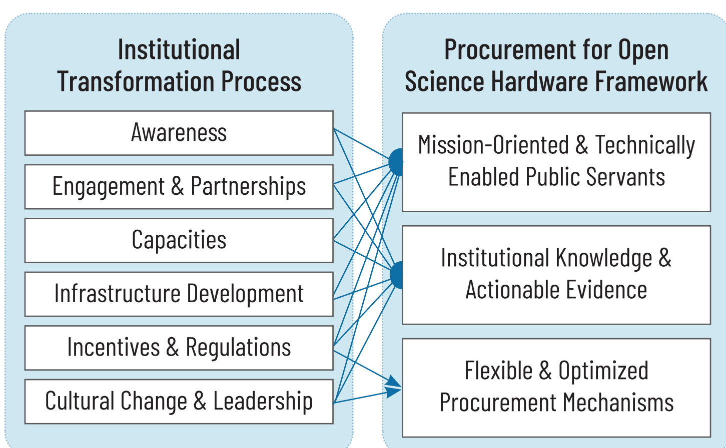


Source: Author's elaboration based on literature review and interview findings.

Public Procurement Innovation Model

Using thematic cluster analysis to interview excerpts, and a literature review, a conceptual model of public procurement innovation was constructed. This model identifies the necessary variables to initiate change in government agencies' procurement processes. The theoretical model recognizes two components: an Institutional Transformation Process and Procurement Innovation Determinants. When both are in place, public procurement innovation can arise.

Figure 3: Public Procurement Innovation Model



Source: Author's elaboration based on literature review and interview findings.

The **Institutional Transformation Process** outlined above acknowledges six stages through which organizations progress before achieving institutional innovation[2]. These stages include: **Awareness**; **Engagement & Partnerships**; **Capacities**; **Infrastructure Development**; **Incentives & Regulations**; and **Cultural Change & Leadership** in government innovation.

In the initial stage, **Awareness**, the focus is on increasing the awareness of OScH solutions among government agencies and stakeholders. It is crucial to educate officials about OScH, its benefits compared to proprietary solutions, and how adopting and procuring it helps advance their organization's mission. This stage may involve conducting workshops and seminars for government officials to introduce the concept of OScH and presenting case studies from agencies like NASA and NOAA that have successfully implemented pilot projects.

The **Engagement & Partnerships** stage fosters engagement and builds partnerships between government agencies, open hardware providers, and other actors. Collaboration and dialogue are essential for creating a supportive network and identifying common goals. For instance, establishing a public-private partnership between a government agency and an open hardware foundation or organization to co-develop pilot projects can leverage the expertise and resources of both sectors. An example to this could be the NASA

Developing the necessary skills and capacities within government agencies to effectively evaluate, procure, and implement OScH solutions is the focus of the **Capacities** stage. This includes training programs on public models to procure for innovation and capacity-building initiatives around making the best of open hardware solutions features such as affordability, modularity, and customization. An example could be implementing training programs for procurement officers to enhance their understanding of OScH, supported by educational materials and best practice guides.

Infrastructure Development involves building and upgrading the infrastructure needed to support integrating OScH solutions in government purchases. This includes documenting success stories and good practices and tailoring technological, logistical, and administrative infrastructures to enable efficient procurement and implementation (Jaquith, 2024). For instance, upgrading procurement systems to include specific criteria for evaluating tenders considering OScH solutions and establishing a centralized database of open hardware providers and their offerings.

The **Incentives & Regulations** stage focuses on creating incentives and regulatory frameworks that encourage government organizations to adopt OScH solutions. This includes developing programs that provide financial and non-financial incentives for government agencies to choose OScH solutions, such as challenges or awards for agencies that successfully implement OScH projects. It also involves developing policies that mandate or prioritize open hardware solutions in procurement processes.

The final stage, **Cultural Change & Leadership**, aims to foster a culture of innovation within government agencies and promote strong leadership to drive and sustain institutional change. This involves advocating for the benefits of OScH and encouraging a mindset that embraces new and innovative solutions. Initiatives may include implementing leadership programs to support the advancement of public servants' careers, focusing on individuals who have successfully introduced innovative practices and are promoting innovation in the government's approach. Additionally, these initiatives may involve establishing programs to recognize innovative projects or teams and fostering a culture of ongoing improvement and openness to new ideas within government agencies.

The combination of these stages establishes the conditions to cultivate the **Procurement Innovation Determinants**, which are essential for achieving institutional innovation. **Mission-Oriented & Technically Enabled Public Servants** are crucial, as they possess a thorough understanding of their organization's mission, and the technical capabilities needed to assess and implement innovative procurement solutions. They recognize the significance of public procurement in driving innovation and have the expertise to evaluate different options effectively.

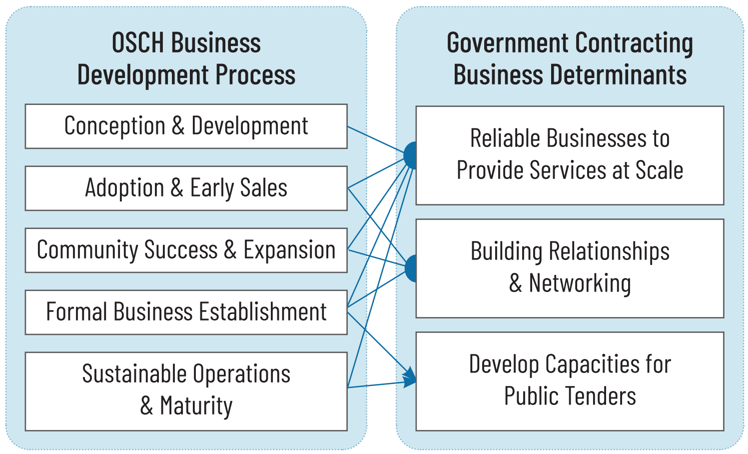
Institutional Knowledge & Actionable Evidence refer to the gathering and use of information within an organization, as well as the evidence that can be used to make decisions and improve procurement practices. Government agencies keep records of past procurement projects, including evaluations and outcomes. It's important to document and include new evidence in the institutional memory to help with future procurement decisions and strategies.

Flexible & Optimized Procurement Mechanisms refer to adaptable procurement processes designed to optimize outcomes. These processes enable the organization to fulfill its mission more efficiently and effectively. The goal is to build agile and well-informed agencies that can easily adopt flexible procurement frameworks, allowing for rapid adjustments without being hindered by rigid procedural constraints.

Open Science Hardware Government Contracting Model

Using thematic cluster analysis to interview excerpts, and a literature review, a conceptual model of OScH for Government Contracting was developed. The theoretical model recognizes two components: an **Open Science Hardware Businesses Development Process**[3], and **Business Determinants for Government Contracting**. When both are in place, conditions are suitable among OSHBs to compete for public tenders and become government providers.

Figure 4: Open Science Hardware Government Contracting Model



Source: *Author's elaboration based on literature review and interview findings.*

OSHBs tend to follow a different development pathway from traditional businesses. Part of this is because at the moment of its conception, OSHBs typically start as scientific projects, where the main drivers are scientific discovery and peer recognition, rather than immediate financial gain. These projects, usually funded by research grants, enable the creation of innovative hardware solutions without the pressure of immediate commercial success. The researchers involved in these projects are often not motivated by profit, but by the desire to advance their fields and contribute to knowledge. OSHBs, with their open source nature, naturally foster collaboration, encouraging community engagement and sharing of designs and improvements. This collaborative model facilitates the adoption of the technology developed since it creates a space where users can become contributors and be part of a larger community.

In the **Conception & Development** stage, OScH projects focus on research and development. This includes securing funding for research, conducting initial experiments, and creating prototypes. The main challenges at this stage include validating the concept and gaining recognition from academic peers. Researchers' efforts in the project are focused on developing research publications, improving prototype performance, and gathering initial feedback from peers.

As OSHBs progress to the second stage, **Adoption & Early Sales** they focus on getting their findings out through presentations at conferences and publishing in journals. They also start selling small quantities within their proximate community. The main challenges during this phase include ensuring that their work can be replicated and adapted to different contexts, gaining support from other researchers, achieving successful knowledge transfer, and managing sales and customer feedback on a small scale. Success is measured by factors such as the number of academic citations, the extent of peer usage, customer feedback, and customer satisfaction.

In the third stage, **Community Success & Expansion**, OSHBs establish credibility, expand usage, and experience informal business growth. Activities include building a user community, improving design based on feedback, providing support and training, and expanding sales outside traditional disciplines. The challenges at this stage involve supporting a growing user base, sustaining funding without formal business structures, and navigating informal sales and business practices. Key metrics include the size and engagement of the user community, the number of successful implementations, broader adoption metrics, establishing a supply chain, and sales figures.

The fourth stage, **Formal Business Establishment**, marks the transition to a formal business. This involves securing additional cash flow to support operations and scale, refining the product for broader use, and establishing sales strategies, customer support, and sustainable supply chain and distribution mechanisms. Often, this stage requires bringing in co-founders with business expertise. The main challenges are managing the shift from research to business operations, maintaining innovation while focusing on business sustainability, and integrating new business processes. Success is measured by formal business registration, established supply chain and distribution networks, customer support systems, increased sales, and market reach.

In the final stage, **Sustainable Operations & Maturity**, OSHBs focus on ensuring long-term viability and impact. Activities include establishing a sustainable business model, maintaining innovation, expanding reach, and solidifying market presence. The challenges involve balancing the business's open nature with traditional commercial goals, sustaining financial health, continuous product improvement, and customer satisfaction. Key metrics for this stage include ensuring long-term financial health, fostering continued innovation, developing capacities to increase market share, achieving broad and sustained adoption across sectors, retaining repeat customers, and establishing brand recognition.

OSHBs can become reliable vendors for government procurement, but to be successful, they need to develop specific capabilities. In the **Business Determinants for Government Contracting** component three main characteristics are described. The first one is the imperative to establish themselves as **Reliable Businesses Capable of Providing Services at Scale**. This involves creating robust business operations, which include consistent production processes, quality control measures, and a dependable supply chain. Ensuring product reliability and maintaining high standards are crucial, as government contracts often require large quantities of products or services delivered consistently over time. Additionally, effective customer support systems must be in place to handle any issues that arise and to ensure continued satisfaction and compliance with contractual obligations.

Secondly, OSHBs must **Build Relationships & Networks** that help them to better understand and navigate the government procurement ecosystem. This involves gaining a deep understanding of the procurement processes, which can include multiple stages such as tender announcements, bidding, evaluation, and contract award. They need to be well-versed in the regulations and standards that govern government contracts, including compliance with legal and financial requirements. Understanding these processes helps in identifying the right opportunities and preparing competitive bids. Building relationships with key stakeholders, such as procurement officers, industry experts, and existing government vendors, can provide valuable insights and guidance. These relationships can also help in anticipating changes in procurement policies and in leveraging informal networks to gain support and advice.

Thirdly, OSHBs need to **Develop Capacities** to compete in and win public tenders. OSHBs face similar challenges as Small and Medium Enterprises (SMEs) in this regard, such as obtaining necessary certifications and accreditations that demonstrate their capability to meet government standards. Meeting stringent regulatory requirements, such as safety standards and environmental regulations, is often a significant hurdle. OSHBs must also prepare to provide financial guarantees and assurances, which can be difficult without substantial financial reserves. Managing the logistics of large-scale service delivery, including production, supply chain management, and distribution, requires careful planning and execution. Furthermore, dealing with the bureaucratic processes involved in submitting bids and proposals can be complex and time-consuming. Overcoming these challenges requires strategic planning, investment in capabilities, and often, collaboration with partners who have experience in government procurement.

Recommendations and Steps Ahead for Public Procurement Innovation

Not every issue requires the immediate creation of a new policy, especially when trying to bring about cultural change in risk-averse and bureaucratic organizations, such as government agencies. Hastily implementing poorly researched policies can hinder progress. Therefore, we recommend taking an incremental approach. This process should start by raising awareness among government officials to familiarize them with the concept. Then, it should move on to capacity building, testing, developing pilot programs, and finally scaling to the entire agency or government level through policy development.

Public servants within government agencies often lack awareness of OScH, which hinders their procurement and adoption. The first step to increasing adoption is to **raise awareness** and advocate for OScH. Organizations need to consider how OScH solutions can help them advance their missions. By **understanding the alignment between OScH and organizational missions and goals**, these institutions can start considering OScH as their preferred solution. This process might be more straightforward for some government entities than for others, given their specific mandates. For example, agencies like NASA and NOAA may find it easier to align with OScH due to their interest in democratizing the adoption of scientific research and innovation, compared to the US Department of Defense, which has different priorities.

Identifying champions within the organization is crucial in making the case for OScH and raising awareness. Internal champions are individuals within the organization who are passionate about OScH and can advocate for its benefits. They play a key role in educating their colleagues, addressing misconceptions, and demonstrating the value of OScH through concrete examples and success stories. Champions can also help build a coalition of support, fostering a culture that embraces innovation and open science principles. Additionally, these individuals can also serve as translators or connectors between agencies and other entities where OScH development and activities are happening. Lack of visibility from government agencies of the developments in the OScH space seems to be among the largest challenges to overcome. Their influence and credibility within the organization make it easier to advocate for these solutions and overcome resistance and drive the adoption of OScH solutions, ultimately leading to more informed and strategic procurement decisions.

It is important to develop **educational materials for decisionmakers**, such as government procurement officers, to introduce them to the advantages and procedures involved in acquiring open source hardware. These materials should cover licensing options, connections with existing industrial policies, and strategies for addressing potential conflicts. For instance, they should highlight situations where adopting open source hardware is complementary to existing efforts and advisable. One example is integrating open source hardware into educational initiatives where flexibility and customizability are critical, such as in STEM programs at schools and universities. The materials should also outline situations where specific criteria must be implemented. For example, when procuring open source hardware for healthcare applications, it is essential to ensure that the hardware meets strict regulatory standards and is compatible with existing medical devices and systems. Criteria to implement could include compliance with health and safety regulations, interoperability with existing equipment, and robust support and maintenance plans. Conversely, there are situations where adopting open source hardware might pose risks and contradictions, making it inadvisable. For instance, in highly sensitive national security applications where the utmost confidentiality and proprietary control are required, open source hardware may not be suitable due to potential vulnerabilities and the need for stringent security measures. By providing such comprehensive educational materials, we can ensure that those responsible for procurement decisions are well-versed in open source alternatives and **increase their confidence**, which enhances the likelihood of their adoption. In addition, creating **support networks** or working groups within government agencies that focus on OScH can be very beneficial. These groups can share best practices, offer technical assistance, and advocate for the use of open solutions.

Forming partnerships with companies, non-profits, and academic institutions specializing in OScH is essential. These partnerships can help bridge the gap between government needs and the solutions available in the market. For example, academic institutions often have cutting-edge research and development capabilities, while nonprofits can offer insights into community needs and potential social impacts. Companies, on the other hand, can provide the technical expertise and scalability required for practical implementation. These collaborations can facilitate a productive dialogue that allows all parties to understand each other's goals and constraints. This dialogue is crucial for **developing calls for tenders that are appropriately tailored** to the unique characteristics of these companies. For instance, many OScH organizations operate on different business models than traditional hardware companies, emphasizing transparency, collaboration, and open source principles. Understanding these nuances can sensitize and better equip government agencies to create tender documents that are more inclusive and reflective of the capabilities of the OScH community.

Additionally, **engaging with the wider OScH communities and end-users** is vital. This engagement helps to identify specific needs, gather feedback on potential solutions, and co-create hardware that is fit for purpose. By involving a diverse set of stakeholders, including researchers, educators, and community organizations, the procured hardware is more likely to meet the varied requirements of different users. This **participatory approach** ensures that the solutions are practical, widely applicable, and more likely to be adopted successfully. For example, regular workshops, hackathons, and community forums can be organized to solicit input and iterate on designs in collaboration with end-users, ensuring that the final products are both innovative and user-friendly. For instance, consider a public tender issued by a government agency to develop a low-cost environmental monitoring device. The tender could include a requirement for the winning bidder to conduct a series of hackathons and community forums as part of the development process. These events would bring together local community members, environmental scientists, educators, and other stakeholders to collaborate on the design and functionality of the device. Through these hackathons, the development team can gather input on essential features, usability concerns, and practical applications of the device.

After initial prototypes are created, community forums could be held to test and provide feedback on these prototypes. Participants could share their experiences, suggest improvements, and identify any issues with the current design. These **feedback loops** ensure that the final product is not only innovative but also aligns with the real-world needs of its users. By embedding this participatory approach within the public tender process, the government agency ensures that the final product is co-created with end-users, enhancing its practicality, relevance, and likelihood of successful adoption. This method also demonstrates a commitment to community engagement and the principles of open innovation, fostering greater trust and collaboration between the government and its stakeholders.

Establishing **innovation test beds** is another critical strategy. Innovation test beds are **controlled environments** where government agencies can experiment with and evaluate OScH. These test beds provide a safe space to trial new technologies, gather data, and refine processes without the pressures and risks associated with full-scale deployment. By using test beds, governments can identify potential issues, understand the required infrastructure, and develop best practices for integrating OScH into their operations. For example, a government agency might set up an innovation test bed to evaluate the use of OScH in environmental monitoring. In this controlled setting, they can test the hardware's accuracy, durability, and integration with existing systems. They can also assess logistical aspects, such as maintenance needs and data management. The insights gained from these test beds help mitigate risks by ensuring that any potential problems are identified and addressed before the technology is rolled out more broadly. Overall, pilot projects and innovation test beds play a critical role in **reducing uncertainty** and demonstrating the value of OScH solutions. They provide governments with the **evidence and confidence** needed to support the transition from traditional proprietary systems to innovative, open source alternatives.

It is crucial to **launch pilot projects** to test and demonstrate the feasibility and benefits of OScH in real-world government applications. Governments tend to be risk-averse by nature, often preferring to avoid unproven technologies due to the potential risks involved. By initiating pilot projects, governments can implement OScH solutions on a smaller scale in specific departments or for particular tasks. This allows them to assess the practicality, effectiveness, and benefits of these solutions without committing to large-scale adoption right away. Successful pilot projects can serve as valuable **case studies**, providing concrete examples of how OScH can be effectively used in government operations. They showcase benefits such as cost savings, increased transparency, and enhanced functionality. These case studies can then be used to **build momentum** for broader adoption across various government agencies. They help to illustrate the tangible benefits and mitigate concerns, making it easier to advocate for wider implementation of OScH solutions.

One of the major challenges for the adoption of OScH is the lack of **documentation of success stories** where an OScH solution demonstrated parallel or superior performance compared to proprietary solutions. Currently, there is a prevailing perception that OScH solutions are less reliable than proprietary products. This mindset is a significant barrier to wider adoption, and overcoming it requires changing how OScH is perceived. To address this challenge, it is crucial to collect and disseminate case studies of successful OScH projects within the government. These case studies should highlight instances where OScH solutions have been effectively implemented and have outperformed their proprietary counterparts. For example, a case study might describe how an open source environmental monitoring device used by a government agency provided more accurate data, was easier to customize, and resulted in significant cost savings compared to a proprietary device. Such examples provide concrete evidence of the viability and advantages of OScH, helping to shift perceptions and **build confidence** in these solutions. Additionally, these case studies should **emphasize the broader economic and social impacts** of procuring OScH. For instance, showcasing how OScH solutions can lead to cost savings by eliminating licensing fees and reducing procurement costs can be very persuasive. Highlighting instances where OScH has spurred innovation—such as through community-driven improvements and rapid iterations—demonstrates the dynamic potential of open source solutions. Furthermore, illustrating the inclusivity of OScH, where diverse groups of researchers, educators, and community members can access and contribute to the development of scientific tools, underscores the social benefits of open source adoption. This approach not only **addresses misconceptions** about reliability but also **showcases the tangible benefits of open source solutions**. Over time, this can lead to a cultural shift within the government, where OScH is seen as a viable, if not superior, alternative to proprietary products. The goal is to create a robust body of evidence that supports the integration of OScH into government procurement practices, thereby fostering a more innovative, cost-effective, and inclusive approach to public sector technology adoption.

Policy development and **cultural change** are more likely in a world with extensive expertise and a wealth of documentation and success stories at this hypothetical stage. When agencies have access to a broad base of knowledge and real-world examples demonstrating the success of OScH solutions, they can use this information to guide their policy-making and cultural initiatives. Agencies with a substantial understanding of these practices can make the policy development process more informed. This extensive expertise means that policymakers are aware of what works and what does not, based on previous implementations. For example, if numerous documented cases show that OScH solutions lead to cost savings and increased innovation, these insights can inform policy decisions. Policymakers can draw on these success stories to craft policies that are practical, effective, and tailored to the specific needs of government agencies. With this wealth of documentation, policymakers can create effective frameworks to support the swift adoption of OScH. These frameworks can include procurement guidelines, standards for evaluating OScH solutions, and incentives for adoption. For example, policies might mandate the inclusion of open source options in all relevant procurement processes, provide tax incentives for companies developing OScH, or offer grants for agencies piloting OScH projects. By having these policies in place, the **transition to OScH becomes more structured and predictable**. When substantial evidence of the benefits of OScH exists, it is easier to advocate for a cultural shift towards open source solutions. A comprehensive and incremental approach, like the one outlined here, ensures that the adoption of OScH solutions is supported by clear evidence, reducing resistance and paving the way for successful implementation.

Conclusion

This report highlighted the potential of OScH to foster innovation, collaboration, and inclusivity in scientific research and development through government procurement practices. While adopting OScH presents significant challenges, such as misconceptions about open source solutions, bureaucratic inertia, path dependencies, and the influence of established vendors, the opportunities it offers are substantial.

By using government procurement to create demand for OScH, supporting small and medium enterprises, and promoting transparent and reproducible research, government agencies can play a crucial role in advancing scientific progress and addressing global access to advanced scientific tools. The case study of CERN provides a compelling example of how innovative procurement strategies can overcome these challenges, offering valuable lessons for US government agencies.

The recommendations identified were: raising awareness among government officials about OScH; building capacity through training and educational materials; identifying and supporting internal champions to advocate for OScH; developing educational resources for procurement officers; forming partnerships with OScH-focused companies, nonprofits, and academic institutions; engaging with wider OScH communities and end-users to co-create solutions; establishing innovation test beds and launching pilot projects to demonstrate feasibility; documenting success stories to shift perceptions about OScH reliability; and using extensive expertise and documentation to inform policy development and foster cultural change within government agencies.

The theoretical framework presented in this report offers a comprehensive roadmap for integrating OScH into government procurement practices, emphasizing the need for a collaborative and informed approach. By following these recommendations, government agencies can enhance their procurement processes, drive innovation, and contribute to a more open scientific ecosystem.

If the current trend continues, government procurement processes will continue to favor proprietary solutions, which could slow down the progress of innovation and technological advancements resulting from public investments. The lack of awareness and understanding of OScH will perpetuate misconceptions about its reliability and effectiveness. This stagnation will cause missed opportunities for cost savings, increased transparency, and enhanced functionality offered by OScH. Furthermore, continuing to provide options to purchase only proprietary solutions, which have been severely criticized for hindering innovation. Ultimately, the current state will hinder progress toward more inclusive, innovative, and cost-effective public sector technology solutions, leaving government agencies ill-equipped to address evolving scientific and technological challenges. This report lays the groundwork for policy development and strategic planning, aiming to support the adoption of innovative procurement practices and foster synergies between public investments and technological advancements.

Appendices

Appendix 1: Methodology Appendix

Objective

The report aimed to landscape the state of government procurement for OScH solutions in the United States. This report follows on the conversations and advancements drafted in the reports "Open Hardware: An Opportunity to Build Better Science" and "Open Science Hardware: A Shared Solution to Environmental Monitoring Challenges."

Interview Process

This report was created from interviews with various actors in the OScH space, including researchers, advocates, business owners, entrepreneurs, and government representatives working either in government procurement or government research facilities. The interviews were conducted primarily through online video calls, with a few conducted via phone and in person, ensuring flexibility and accessibility for all participants. Based on the principles of grounded theory, this study conducted over 20 interviews with policymakers, OSHB owners, practitioners, advocates, and researchers to better understand the challenges of public procurement for OScH.

Sampling Method

The interviewees were identified from previous efforts and collaborations within the OScH community, as well as through recommendations made by these interviewees. The selection process involved using theoretical sampling to identify interviewees, and a purposive sampling method to select individuals with significant experience or insight into OScH and government procurement processes.

Data Collection

The interviews were semi-structured and mostly conversational, allowing for in-depth exploration of each participant's experiences and perspectives. The recordings were made with the participants' consent, and detailed notes were taken to capture key insights and themes. Three rounds of data collection were conducted until reaching theoretical saturation.

Data Analysis

The interviews were transcribed and analyzed to identify common themes, opportunities, and challenges related to government procurement of OScH solutions. Data was categorized into themes and sub-themes using coding techniques such as the Gioia method [4], axial coding, and thematic clustering analysis. The analysis involved dividing the interviews into two groups.

The first group comprised decisionmakers and government officials, focusing on procurement processes, challenges, and strategies for implementing opportunities. This led to the development of a conceptual model for Public Procurement Innovation, identifying necessary factors within government agencies to implement innovations in the procurement process, enabling them to purchase or give preference to OScH solutions.

The second group included OSHB owners, practitioners, advocates, and researchers. Their interviews aimed to understand the challenges these businesses face in competing in public bids or tenders, and the opportunities they identify. This led to the development of a second conceptual framework on Open Science Hardware Business Innovation, explaining the conditions under which OSHBs can navigate government procurement processes successfully.

A theoretical framework for government procurement of OScH was constructed, incorporating the analysis of the two conceptual models. This framework identifies necessary conditions for this market to be feasible and mutually beneficial for both parties. The components of the theoretical framework were validated in a case study, specifically the procurement process at CERN, demonstrating the practical applicability and robustness of the proposed framework.

Ethical Considerations

All participants were informed about the purpose of the study, and their consent was obtained before conducting the interviews. Confidentiality was maintained by anonymizing personal and organizational identifiers in the report, except when explicit consent for identification was given, like in the case study. Ethical standards were adhered to throughout the research process to ensure the integrity and reliability of the data.

Limitations

The primary limitation of this methodology is the reliance on qualitative interviews, which may introduce biases based on the participants' perspectives. Additionally, the purposive sampling method may not fully represent all stakeholders in the OScH community. Despite these limitations, the insights gained provide valuable contributions to understanding the state of government procurement for OScH solutions.

Appendix 2: Public Procurement Innovation Model Gioia Data Structure

First Order Concepts	Second Order Themes	Aggregate Dimensions
Current procurement processes are inefficient	Procurement Process Inefficiencies	Systemic Issues in Procurement
Agencies use a one-size-fits-all approach		
Challenges in funding and procurement processes	Challenges in Procurement Processes	
Legal entity or vendor requirement in procurement		
Navigating university procurement processes		
Unique challenges of hardware vs. software procurement		
Open source solutions are often overlooked	Promotion & Adoption Strategies	Strategic Promotion & Adoption
Changing the narrative to promote open source adoption		
Advocacy for open hardware adoption		
Developing best practice guides		
Celebrating small successes		
Mandating open source hardware in government funded grants		
Adopting open hardware to avoid vendor lock-in	Vendor Lock-In & Tenders	
Call for tender processes to involve companies in open hardware production		
Strategies to avoid vendor lock-in, like having two winners in tenders		
Importance of medium-sized companies for support		
Monetizing aspects of open hardware to obtain resources		
User-friendly product design	Design & Manufacturing of Open Source Hardware	Innovative Design & Implementation
Advantages of non-profit open-source model		
Focus on local manufacturability		
Balancing open licensing with business needs		

Source: Author's elaboration based on interview findings.

Appendix 3: Open Science Hardware Government Contracting Model Gioia Data Structure

First Order Concepts	Second Order Themes	Aggregate Dimensions
Challenges in sustaining open science projects long-term	Sustaining Open Science Projects	Long-term Viability & Sustainability
Potential of altruistic volunteer-driven models		
Challenges of funding and sustaining open science/citizen science projects		
Potential of volunteer-driven models and philanthropic funding		
Choosing permissive open source licenses to accelerate adoption	Open Source Licensing & Commercialization	
Challenges in negotiating licensing deals with large companies		
Benefits of pre-selling and crowdfunding		
Importance of pricing products to support ongoing work		
Operational efficiency through customization for different markets		
Challenges with cybersecurity and legal requirements in government contracts		
Commercializing open source hardware to disseminate products		
Governance and community involvement during commercialization		
Successful open science collaborations (e.g., COVID-19 dashboard)	Successful Collaborations & Initiatives	Effective Partnerships & Collaborations
Successful collaborations (e.g., NASA's open data initiatives)		
Pilot programs to test open source hardware solutions		
Suitability of scientific equipment and environmental monitoring for pilots		
Role of champions and external talent	Role of Champions & External Talent	
Opportunities for champions and external talent in driving innovation		
Champions as connectors between agencies and projects and businesses		
Barriers in traditional government procurement processes	Challenges in Government Procurement	Navigating Institutional Policy Barriers
Challenges in government procurement for open source hardware		
Need for legislative support and agency mission alignment for open science		
Opportunities for creating guides and strategic plans	Strategic Planning & Guides	
Creating guides, playbooks, and strategic plans for open science procurement		

Source: Author's elaboration based on interview findings.

References

Arancio, J., Tirado, M. M., & Pearce, J. (2022). Equitable research capacity towards the sustainable development goals: The case for open science hardware. *Journal of Science. Policy & Governance, 21*(2).

Boldrin, M., Allamand, J., Levine, D. K., & Ornaghi, C. (2011). Competition and innovation. *Cato Papers on Public Policy*, 1, 2011. https://ssrn.com/abstract=2235077

Dosemagen, S., Liboiron, M., & Molloy, J. (2017). Gathering for open science hardware 2016. *Journal of Open Hardware, 1*(1).

Edler, J., & Georghiou, L. (2007). Public procurement and innovation—Resurrecting the demand side. *Research Policy, 36*(7), 949-963.

Edler, J., & Uyarra, E. (2013). Public procurement of innovation. In *Handbook of Innovation in Public Services* (pp. 224-237). Edward Elgar Publishing.

Edquist, C., & Zabala-Iturriagagoitia, J. M. (2015). Pre-commercial procurement: A demand or supply policy instrument in relation to innovation? *R&D Management, 45*(2), 147-160.

Edquist, C. (1997). *Systems of innovation: Technologies, institutions and organizations*. University of Illinois at Urbana-Champaign's Academy for Entrepreneurial Leadership Historical Research Reference in Entrepreneurship. https://ssrn.com/abstract=1496222

Fernando, P., & Kuznetsov, S. (2020). OScH in the wild: Dissemination of open science hardware and implications for HCI. In *CHI 2020 - Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems,* Article 3376659 (Association for Computing Machinery. https://doi.org/10.1145/3313831.3376659

Fishenden, J., & Thompson, M. (2013). Digital government, open architecture, and innovation: Why public sector IT will never be the same again. *Journal of Public Administration Research and Theory, 23*(4), 977-1004.

Frangos, M., Pearce, J. M., Brastaviceanu, T., Mahmoud, A. A., & Khalid, A. (2016). Democratising design in scientific innovation: Application of an open value network to open source hardware design. *Cumulus Working Papers,33/(6),* 333-339. https://ssrn.com/abstract=3331281 or http://dx.doi.org/10.2139/ssrn.3331281

Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2013). Seeking qualitative rigor in inductive research: Notes on the Gioia methodology. *Organizational research methods, 16*(1), 15-31

Hiatt, J. (2006). *ADKAR: a model for change in business, government, and our community*. Prosci.

Hsing, P., & Johns, B. (2023). Open science hardware for realising globally equitable knowledge production. *Edinburgh Open Research*.

Jaquith, W. (2024, January). Preventing lousy vendors from bidding on your custom software project. *Waldo Jaquith's Blog Post.* https://waldo.jaquith.org/blog/2024/01/attracting-better-vendors/

Keller, O., Appelhoff, S., Paffhausen, B., & Wenzel, T. (2023). Development and sharing of open science hardware: Lessons learned from Wikimedia fellowships. *Research Ideas and Outcomes, 9*, e95174.

Lewis, V. L., & Churchill, N. C. (1983). The five stages of small business growth. *University of Illinois at Urban*a-Champaign's Academy for Entrepreneurial Leadership Historical Research Reference in Entrepreneurship.

Marquis, C., & Tilcsik, A. (2013). Imprinting: Toward a multilevel theory. *Academy of Management Annals, 7*(1)*, 193-243.* https://doi.org/10.5465/19416520.2013.766076.

Mazzucato, M. (2021). Markets: Shaping not fixing. In *Mission Economy: A Moonshot Guide to Changing Capitalism*. HarperCollins Publishers.

Moritz, M., Redlich, T., Grames, P. P., & Wulfsberg, J. P. (2016, September). Value creation in open-source hardware communities: Case study of Open Source Ecology. *2016 Portland International Conference on Management of Engineering and Technology (PICMET)* (pp. 2368-2375). IEEE.

Moritz, M., Redlich, T., & Wulfsberg, J. (2018). *Best practices and pitfalls in open source hardware*. In *Proceedings of the International Conference on Information Technology & Systems* (ICITS 2018) (pp. 200-210). Springer International Publishing.

Moritz, M., Redlich, T., Günyar, S., Winter, L., & Wulfsberg, J. P. (2019). On the economic value of open source hardware: Case study of an open source magnetic resonance imaging scanner. *Journal of Open Hardware*, *3*(1).

Open Government Partnership. (2024). United States Action Plan 2022-2024: Innovative techniques to engage the public in public procurement (US0124). *Open Government Partnership.* https://www.opengovpartnership.org/members/united-states/commitments/US0124/

Pearce, J. (2020). Economic savings for scientific free and open source technology: A review

HardwareX, 8, e00139. https://doi.org/10.1016/j.ohx.2020.e00139

Rolfstam, M. (2015). Public procurement of innovation for a better world: A consolidation or a new beginning? *Innovation: The European Journal of Social Science Research, 28*(3), 211-219.

Serrano, J. (2016). Open hardware and collaboration. *11th Intl. W. on Personal Computers and Particle Accelerator Controls*, Campinas, Brazil.

Uyarra, E. (2016). The impact of public procurement of innovation. In *Handbook of Innovation Policy Impact* (pp. 355-381). Edward Elgar Publishing.

Endnotes

1 Call for tenders, or call to receive bids, is a formal invitation for suppliers and contractors to submit bids to provide goods, services, or complete projects.

2 The Institutional Transformational Process is an adaptation of the ADKAR model (Hiatt, 2006), a goal oriented management model that can be used to understand and manage change at the individual and organizational level. This model has been adapted and empirically used in the past to specifically address the unique challenges and dynamics of non profit organizations.

3 The Open Science Hardware Businesses Development Process component outlined depicts the evolutionary stages of OSHBs. It is based on a model developed by Churchill & Lewis to understand the growth and challenges encountered by small businesses (Lewis and Churchill 1983). This model has been adapted to specifically address the unique challenges and growth dynamics of OSHBs.

4 The Gioia methodology is a qualitative approach for developing grounded theory focusing on data structure, grounded model development, and narrative presentation (Gioia et al, 2013).

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