Project details
Abstract of project proposal
Open access publishing, open data and free and open source software have become important pillars of responsible research and innovation (RRI), an approach that wants to maximise the integrity and impact of research. Presently, a new school of thought is emerging which aims to establish an open hardware (OH) strategy for academia. OH is extending the principles of free and open source from software into physical products, enabling hardware reuse and quality control. It also fills a gap in the promotion of FAIR data principles (seeking to make data Findable, Accessible, Interoperable and Reusable) by German and European funding agencies. This project will contribute to this mission through new methods, tools, guidance, standards and awareness building, in order to evaluate and preserve the replicability of hardware in academia. We will pool expertise in hardware evaluation at the TUB, academic hardware making at the FUB and scholarly communication and data management at the HUB. Solutions will be designed according to our analysis of community practices. They will be prototyped and verified within chosen hardware projects of the partners in the fields of automation, physical metrology and virtual reality applications. Lessons learned during the project will feed open educational resources (OER). The importance of OH for society has been well demonstrated during the first wave of COVID-19 when open hardware makers started to deliver 3D-printed face shields to medical professionals in a time of great need. Our cross-disciplinary and practice-oriented approach will act as a centre of competence in the Berlin University Alliance for the development of novel standards and tools for open hardware documentation, evaluation and publication. Open, FAIR hardware especially presents an opportunity for new career paths and an alternative to traditional intellectual property rights (IPR) practices, reflecting the wider role of academic research in society.

Planned Starting Date of Project	01.06.2021
Duration of project	24
Thematic Funding Line	Belongs to both
Core Topics of the Berlin University Alliance	Application-oriented
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Towards open and FAIR hardware

short title: **Open.Make**

24 months project starting in June 2021

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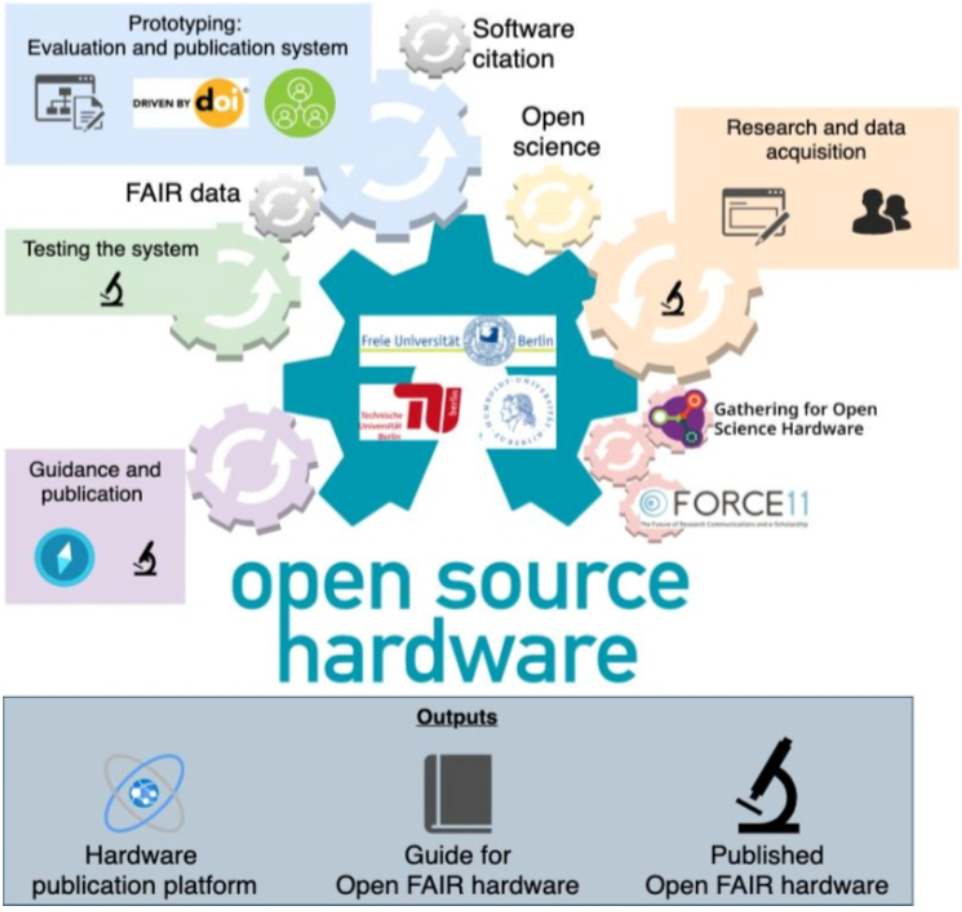
Visual abstract



Description of research contents and other details
Short project description
Introduction Experimental science is typically dependent on hardware: equipment, sensors and machines. While researchers are tasked with building, testing and using these machines, the lack of organised technical documentation and quality control leads to waste of resources in many ways, sometimes at a single lab level: duplicated work, inaccuracies in research results and most notably, difficulties in results comparisons and reproduction. Hardware documentation is not only a time-consuming process, it is also a non-trivial task that requires a structured approach. In absence of guidance and acknowledged community standards for the evaluation and dissemination of hardware, it is complex for researchers to share their hardware solutions. Moreover, the task of documenting hardware happens to suffer a general lack of both resources and recognition, something that affects labs as well as joint research projects of all sizes. Research data and software are at the same time published using specific licences, specific platforms (see https://blog.datadryad.org/2021/02/08/doing-it-right-a-better-approach-for-software-amp-data/), specific evaluation mechanisms (data curation and software review) and the community is recommending the citation of these instances instead of the research paper (Katz et al. 2021). As a consequence, the publication of datasets and software starts to be recognised as an important research output (see guideline 13 of the DFG codex in Deutsche Forschungsgemeinschaft, 2019). In contrast, the recognition of good scientific practices in hardware development is lagging behind. Indeed, there is no dedicated publication system for hardware and there is no direct mention of hardware in the DFG codex (Deutsche Forschungsgemeinschaft 2019). Also, in the CREDIT initiative that promotes the creation of incentives for non-traditional contributions (Vasilevsky et al. 2020), hardware development has so far not been addressed. Accordingly, there is a lack of infrastructure support and incentives for researchers to provide documentation for their hardware designs, especially as there is often no quality assessment of hardware in academia. In research projects, defining quality criteria as part of hardware development requires considering issues such as project goals, stakeholder needs and geographical contexts. These are translated into technical requirements against which technology is prototyped, demonstrated, optimised and/or qualified. However, hardware development according to OH principles presents specific requirements such as transparency, accessibility and replicability (Balka et al. 2010). The latter presents a critical factor for RRI and a putative high return of investment for the society (Pearce, 2015). A key question on open hardware in recent years has been to ask “how open” it is (Bonvoisin and Mies 2018). Emerging open hardware maker communities are starting to address the issues of hardware openness, as well as recognition mechanisms for their work. They consist of enthusiastic researchers and practitioners who engage in hardware co-creation. Open hardware (also referred to as open source hardware) describes tangible products “for which a free right of any use belongs to the general public and whose documentation is completely available and freely accessible on the Internet” (DIN e.V. 2020a). It means sharing designs for equipment that anyone can reuse, replicate, build upon or sell, as long as they attribute the developers on whose shoulders their work stands. But, similar to datasets that can be open and useless, open hardware can only reach its full potential if it is also FAIR (findable, accessible, interoperable

and reusable) and if its quality is assessed. Again, similar to the situation with data, hardware might also be FAIR without being open.

In this project, we will adapt the infrastructure, quality control and recognition system available for data and software to the hardware documentation and thereby lend credibility to open, FAIR hardware in academia. In the long term, by enabling the recognition of hardware documentation as an important research task, our work will lead towards unlocking the potential of OH for science and society.

Project objectives

Open.Make defines the following general and specific objectives:

General objective: Create and test open infrastructures, guidance, standards and tools to facilitate the documentation, evaluation and publication of open, FAIR hardware in academia. This will facilitate reproducibility and dissemination of hardware and build the foundation for a greater recognition of hardware making skills in academia.

Specific objective 1: Develop and demonstrate a prototype for a hardware evaluation and publication system.

This involves:

- the creation of an evaluation system specific for FAIR and open hardware (WP1-2);

- the adaptation of publication pathways used for data and software (WP2);

- the verification of developed solutions within ongoing hardware projects of the partners, in the fields of automation, medical devices, physical metrology and virtual reality applications (WP2); and

- the exploration of incentive mechanisms to foster the reproducibility of hardware irrespective of the research domain (WP1-2-3).

Specific objective 2: Provide researchers with theoretical and practical guidance for their work along the whole process of open and FAIR hardware development.

This includes:

- the analysis of current workflows in hardware design and dissemination in the context of academia, their successes and shortcomings (WP1);

- a dissection of the certification process of some chosen hardware pieces in neuroscience, robotics, medicine and physics (WP2);

- the transformation of the lessons learned into teachable units, checklists and templates; and

- the editing of an open book similar to the Turing way book (Community et al. 2019) which is produced in the field for Reproducible Data Science guidance. This book will present the teachable units in a compact form (WP3).

Specific objective 3: Build the foundations for a recognition system for researchers developing FAIR hardware.

This involves:

- the study of the current incentive mechanisms for hardware developers (WP1);

- the creation of seals of quality to append to hardware and their developers (WP3);

- the development of a hardware citation concept, inside an international working group (WP3); and

- pro-active cooperation with other relevant projects, actors and initiatives on the wider establishment of evaluation procedures and indicators for open, FAIR hardware (WP1-3).

Research Quality and Open Science

The project Open.Make fully addresses Line 1: Research Quality and specific aspects of Line 2: Open Science of this call.

Responses to Line 1: Research Quality

Area 1 - Research quality in different disciplines: As mentioned, this project will bring incentives and an evaluation system to motivate and monitor the production of FAIR hardware, which will eventually raise the quality of the hardware produced. Traditionally, publicly funded research projects tend to seek intellectual property (IP) protection through patents, design and trademark application. While this is common practice, RRI involves holding research to high ethical standards including the reproducibility of research results. This project will enable researchers and joint research projects to easily publish hardware according to FAIR data principles. This provides an alternative to IP and a sustainable path that ensures unhindered reuse of products by any actor interested in making use of and benefiting from these resources. Furthermore, verifying developed solutions within ongoing hardware projects of the partners in the fields of automation, medical devices, physical metrology and virtual reality applications will ensure that different disciplines are taken into account. These include biology, neurology, medicine and physics among many others.

Area 2- Evaluation and assessment procedures: We will create new processes and infrastructure for the evaluation of hardware replicability and publication. While the former develops qualitative methodology to assess the conformity of hardware with OH and FAIR principles, the latter enables the crediting of hardware makers for their work. Since these research outputs are largely unrecognised in academia, this will lead to new quantitative indicators beyond the visibility of published research articles.

Responses to Line 2: Open Science

Area 1 - Funding of open science practices: We will create evaluation criteria for the quality and openness of hardware produced in research. This will bring hardware at the level of datasets and software in university and provide researchers' indicators, allowing research funders to include new criteria in their choice of funding, promoting open science and open hardware practices. We will support an Open Hardware Makers Curriculum by creating guidelines on the documentation, evaluation and publishing of open, FAIR hardware. In addition, we will promote the use of open infrastructures (independent of publishers) to review and publish open, FAIR hardware, so that we restrict the cost associated with hardware publication.

Area 2 - Analysis of disciplinary framework conditions for open science: As part of the needs analysis for the project's solutions, we will monitor current practices in hardware development, as well as consider motivations of researchers to produce OH. Also, we will also

look into the processes of hiring hardware makers in the lab, looking for ways to improve the adoption of open hardware in the community. In addition, we will map national and international standards for technical documentation and open hardware sharing and promote an international consortium dedicated to build a better framework.

Additional responses to the general call requirements

With this practice-oriented project, the Berlin University Alliance will create a centre of competence for the development of novel standards and tools for hardware documentation and publication. The partners are moreover keen to cooperate with BUA Objective 5: Sharing Resources and the BUA Cross Cutting Themes on issues such as diversity, gender, teaching and internationalization.

Current international research

Open Hardware is a practical phenomenon that was created by grassroots communities at the start of the century. Important steps in the consolidation of the field have been the founding of the OH community projects: Open Source Ecology for a global village construction set in 2003 (OSE, http://opensourceecology.org/); Arduino for low-cost microcontrollers (https://www.arduino.cc/) and RepRap for DIY 3D printers (http://reprap.org/), both in 2005; the introduction of CERN's Open Hardware Repository for collaborative OH development (OHWR, https://ohwr.org/) and CERN's Open Hardware Licence (OHL, https://ohwr.org/cernohl), both in 2011; the formation of the Open Source Hardware Association (OSHWA, https://www.oshwa.org) in 2012; and the formation of the Gathering for Open Science Hardware community (GOSH, http://openhardware.science/) at Cambridge University in 2016 which promotes the democratization of science by DIY ("Do It Yourself") hardware.

Interest in the research community has been growing steadily since 2000. In recent years, dedicated journals have been founded like the Journal of Open Hardware and HardwareX (Elsevier) and there have been special issues / thematic collections in journals such as: Human-Computer Interaction, Design Issues or Design Science. Despite the importance of the open hardware approach focusing on crucial socio-economic trends such as circularity and the creation of a bio-economy, the topic still remains relatively understudied and unknown in science and industry.

This project will create synergies with ongoing research in the H2020 project OPEN_NEXT coordinated by TUB (https://opennext.eu/, grant agreement no. 869984): Among other things, the partners are carrying out research on facilitating design reuse of OH in industry; and demonstrating an open graph database to facilitate design reuse through (semi-)automated structuring of OH modules, called Library of Open Source Hardware (LOSH, https://github.com/OPEN-NEXT/LOSH). We will also work with the Open Knowhow initiative (by MakerNet in which TUB has participated since its foundation in 2019, https://openknowhow.org/), which published a metadata standard to enhance the discoverability of OH on the Internet.

This project will apply and use different toolboxes and advances in software and research data publication. We will introduce the open hardware subject into the FORCE11 community (https://force11.org) that elaborated the FAIR principles and is active in various scholarly communication activities (including for example sustainable research software initiatives, contributor role taxonomies). On the other hand, specific groups in the research data alliance

(RDA, https://www.rd-alliance.org) have been working on data and software citation, so we will team up with them to design hardware citation recommendations. We will also seek collaboration with national research data infrastructure (NFDI) programs, especially with NFDI-neuro (www.nfdi-neuro.de).

We will also closely work with the Open Hardware Makers program, a spin-off project from the GOSH community (https://openhardware.space/). This mentoring program has been continuously developing a curriculum on the basics of open hardware targeted at newcomers (practitioners, makers and researchers).

Work schedule

Achieving the objectives of Open.Make requires continuous collaboration and inter-disciplinary exchanges between the three partners throughout the entire project period. To attain this, the team will establish a structured, collaborative and transformational way of working which seeks to steadily move towards realizing its ambitious goals while keeping a close view on the risks and challenges that may arise.

The working program consists of three work packages (WPs) building on each other like a staircase. Each of them kicks off a new stage of the project from (1) research, to (2) prototyping and testing, to (3) impact maximisation. Each stage is designed to leverage external involvement, espousing the participatory nature of the project's research object.

WP1 will deliver the necessary groundwork by identifying and analysing representative use cases, best practices of open and FAIR hardware development in academia and researcher needs. It will then transform the collected information into requirements. WP2 will prototype and test the evaluation and publication system for open and FAIR hardware in academia. WP3 will maximise impact by providing developing OERs, engaging in standardisation and building awareness. Throughout the project, we will, in addition, use relevant hardware pieces developed by the partners as use cases (see a detailed description in the "Description of practical results and implementation" section).

WP1: Research | M1 - M9

This work package will build the shared knowledge base for the project, through a mixed-method approach of data triangulation.

Methodology: On the one hand, an interview campaign and an online survey will deliver a better understanding of opportunities and shortcomings of open, FAIR hardware practices in academia. In particular, we will find and contact researchers of any discipline who are active or interested in hardware development and conduct semi-structured interviews. The survey will focus on issues such as processes and tools used, researcher needs, pain points and their habits in the documentation and dissemination of the hardware. On the other hand, we will carry out participant observation research on relevant use cases of several hardware pieces that have been developed in the partners' labs and workshops. Cross-analysis of the complementary datasets will allow a balanced picture and crystallization of findings which will allow us to specify the requirement for the hardware evaluation and publication system. We will also seek for additional partners and grow an international network of OH enthusiasts (GOSH), scholarly communication professionals (FORCE11) and data management specialists (RDA).

Tasks:

T1.1 Conducting of survey (HUB)

T1.2 Conducting of interview campaign (TUB)

T1.3 Conducting of participant observation study on the use cases (FUB)

T1.4 Transforming needs into technical requirements (TUB)

T1.5 Building and strengthening international cooperation (HUB)

Deliverable:

D1.1 Report on the technical requirements for the evaluation and publication system, including datasets and findings from the survey, the interview campaign and the participant observation (TUB) | M9

WP2: Prototyping and testing phase | M7-M20

This work package will prototype and test the hardware evaluation and publication system.

Methodology: In addition to quality control, the publication system will provide recognition to the contributors who worked on the project, a long-term archive of the research results, a registration of the work and awareness. Also, usage rights will be clearly specified as to follow the FAIR principles. Last but not least, this publication system will be easy to use and it will possibly be integrated in the workflow of the researchers. To achieve this, we will first map the system in an architecture diagram abstracting its overall structure, as well as the relationships, constraints and interfaces between modules, basing the scope on the requirements we elicited in WP1. This will allow us to work simultaneously on the different modules.

The system will be developed by extending existing software and concepts. The TUB brings in a shared background from an existing functional prototype. This prototype was co-developed with the cooperation partner OHO e.V. (in Gründung) in accordance with the DIN SPEC 3105 specification and runs as a Wiki extension (see https://en.oho.wiki/wiki/About_OHO_Certification_Center#Attest_Project). The HUB brings experience in data publication portals and scholarly communication. We will leverage and adapt existing software and platforms involved in the publication of version-controlled data and software in Git repositories (Zenodo, Dspace, GIN, but also modern publishing, https://oa-pub.hos.tuhh.de/en/). We will provide tools to choose a hardware licence to make FAIR hardware also open. The system will report on contributors' roles using a computer readable solution, so as to build better recognition metrics. In addition, we will define a metadata model for hardware publication. It will adapt and extend previous works from the OpenKnowhow initiative and the LOSH developed in OPEN_NEXT (TUB), in the light of scholarly metadata elements and infrastructure (in particular DataCite).

The main target group will be researchers who will submit or review hardware documentation. The system will provide them with comprehensible and intuitive interfaces using principles of human interface design. For testing, we will evaluate and make the use cases from the partners ready for publication.

Tasks:

T2.1 Analysing the system architecture (FUB)

T2.2 Prototyping of the evaluation system (TUB)

T2.3 Adding an extension for the publication and citation (HUB)

T2.4 Providing process manuals to the users of the system (TUB)

T2.5 Testing of feature frozen version (FUB) with the use cases

Deliverable:

D2.1 Report on prototyped and tested system (FUB) | M20

WP3: Impact maximisation | M12 - M24

This work package implements joint dissemination and exploitation actions.

Methodology

In order to provide OERs for hardware making, we will partner closely with the Open Hardware Maker Program. We will complete their knowledge on specific problems and best practices that we will identify during the analyses of workflows and use cases in WP1 and during the evaluation of hardware in WP2. We will also organise the redaction of an open book, using the technology, workflows and principles used for the redaction of the Turing way book (Community et al. 2019). Furthermore, we will provide researchers with templates and checklists that could guide the organisation of their files. We will develop these tools iteratively including community feedback at different stages of the process, imitating the successful strategy used by the GIN-Tonic team (Colomb et al. 2021). During this phase, we will also develop an implementation strategy for the developed open infrastructure, finalizing our discussions with libraries and IT departments, in order to provide a sustainable instance of the open hardware publication system. Moreover, we will engage in technical standardisation on the used peer to peer review procedure for open hardware in science, involving the authors for the DIN SPEC 3105 to extend it (DIN e.V. 2020a; DIN e.V. 2020b). This phase will see the appearance of hardware and article publication by the consortium and the organisation of an international conference aimed at raising awareness in the OH community.

Tasks:

T3.1 Organisation of the open book writing (guidelines for documenting, evaluating and publishing of OH) (HUB)

T3.2 Publication of reviewed, open and FAIR use cases of hardware pieces (FUB)

T3.3 Engagement in technical standardisation of the evaluation procedure for open hardware in science (TUB)

T3.4 Organisation of an international scientific and practitioners workshop/conference (HUB)

T3.5 Coordination of publishing of journal articles (FUB)

T3.6 Adaptation of the evaluation and publication system to requirements of Berlin university IT infrastructures (HUB)

Deliverable:

D3.1 Synopsis report summarising and compiling the results (HUB) | M24

D3.2 Open book (HUB) | M24

Milestones & means of verification

MS1: Interviews completed: User needs and habits sufficiently analysed permitting to transform them into technical requirements. | M7

MS2: Mapping of architecture diagram for the prototype of the evaluation and publication system for hardware Systems structure, relationships, constraints and interfaces of modules sufficiently abstracted to start development. | M10

MS3: Design freeze of evaluation and publication system prototype: Functional digital infrastructure including interfaces and user instructions ready for testing. | M18

Critical risks for implementation & proposed risk-mitigation measures

R1: Low number of responses for the survey | WP1 | Likelihood: Medium; Impact: Medium - Mitigation: Good time planning; direct invitation and invitation via international communities.

R2: User needs are not sufficiently understood in M7 to transform them into technical requirements | WP1 | Likelihood: Low; Impact: High - Mitigation: Good time planning starting the process as early as possible; continuous monitoring of progress for early-stage problem identification, creating an inviting atmosphere to discuss problems.

R3: Systems structure, relationships, constraints and interfaces of modules is not sufficiently abstracted in M10 to start developing the evaluation and publication system | WP2 | Likelihood: Medium; Impact: High - Mitigation: Same as on R2.

R4: Functional digital infrastructure including interfaces and user instructions is not ready for testing in M16 | WP2 | Likelihood: Medium; Impact: Low - Mitigation: Same as on R2, testing of the concept manually or giving live instruction.

R5: Low readiness of target groups to use the evaluation and publication system | WP3 | Likelihood: very High; Impact: Medium - Mitigation: Address them with attractive user interfaces and contents and communicate clearly the benefits to them; involve hardware communities from the beginning, provide an open infrastructure to allow a re-use of the work once the communities are ready.

R6: Low availability/interest of Berlin universities' IT departments and/or libraries to cooperate with us on the adoption of the evaluation and publication system | WP3 | Likelihood: Medium; Impact: Medium - Mitigation: Solutions will be designed from the start to be aligned with needs and infrastructure of Berlin universities' IT departments and/or libraries; contact them from the beginning and establish a professional interaction on different levels of hierarchy.

Potential use of scientific results

In the project, we will help define best practices in hardware making and ways to measure the quality, FAIRness and openness of hardware, as well as test a new publication path for researchers building hardware. These scientific results will become a building block for the development of new metrics in research, create new career paths for researchers and provide new standards for hardware documentation and sharing.

1. New metrics

We will provide the basis to facilitate monitoring of hardware making activities in universities. This will allow the development of new algorithms and software that will create new metrics to

measure academic successes. We will also implement a contributor role taxonomy that will make it possible to give granular rewards to the researchers, for instance, in the form of open badges (see https://profiles.impactstory.org/ for an example for open access).

2. New career paths

We will create OERs to teach hardware development in academia as a results of our analysis and cooperation with the GOSH community. This content will be on the one hand leveraged by free-lance teachers or the OH community. On the other hand, it will likely lead to the creation of new master classes. Indeed, efforts in the definition of good data management has brought a new career path for data managers and stewards. It leads to the creation of the specific master in Digital Data Management at the HU (https://www.ibi.hu-berlin.de/de/studium/studiengaenge/ddm-master). We foresee the development of a similar curricula for open hardware in the near future.

3. New standards

Open source software has revolutionised the software industry, and open hardware has the potential to have a similar effect in conventional industries. Open hardware is a pillar of open innovation that is promoted by the EU. We believe that our work will therefore be used outside academia on creating new standards for hardware documentation and sharing.

4. New hardware documentation and stronger communities

During the project, different hardware pieces will be evaluated and published as open source hardware. This will maximise their reuse in the scientific community. We hope that this example will be followed by others and that we will be able to demonstrate the benefits of hardware documentation inside and outside academia. Therefore, we will keep a regular exchange on this issue with relevant organisations and communities such as the OSHWA, CERN, GOSH and Wikifactory (social product platform with over 80,000 members from 190 countries and partner of OPEN_NEXT).

Dissemination and exploitation plan:

- Release of a tested prototype of the hardware evaluation and publication system as an open source software

- Mapping a workflow for the evaluation and publication of hardware at the BUA

- Publishing of at least five hardware pieces as use cases

- Publishing (following anonymisation) of three open access datasets related to the analysis of the survey and interview campaigns

- Creation of a FORCE11 interest group

- Writing of at least three blog posts on the FORCE11 website and elsewhere

- Creating an additional part for the DIN SPEC 3105 on an evaluation procedure for open hardware in science

- Editing (and partly writing) an open source book (guidelines for documenting, evaluating and publishing of OH making)

- Publishing at least three journal articles from the disciplines of scholarly communication,

research theory, computer science and design engineering.

- Organise an international workshop/conference in Berlin with at least 50 participants and document and share the results afterwards.

Description of practical results and implementation

#Concept

The concept of Open.Make is mainly to combine hardware evaluation and publication within the frame of supporting infrastructure, tools and guidance, enabling researchers to maximise the reproducibility and dissemination of their hardware. This will build the foundation for greater recognition of hardware making skills in academia. FAIR data, software citation and open science practices are important enablers for hardware publication and their investigation will, without a doubt, be an important basis of this project.

Our hardware evaluation and publication prototype will be based and released as an open source software. This allows for libraries and university IT departments to provide their own hardware evaluation and publication pathways. We will indeed approach IT departments and libraries at the BUA early in the project in order to prepare such implementation and provide a sustainable open infrastructure for OH at the BUA.

Evaluation and publication system description

Evaluation of open, FAIR Hardware needs to follow its own principles. While datasets evaluation is very domain specific and often requires the involvement of data curation specialists and/or automated verification of metadata models, the use of the FAIR principles (Wilkinson et al. 2016) has been a catalyst in the creation of data curation workflows. In contrast, research software peer review is an emerging field, where communities (ROpenSci et al. 2020, the Journal of Open Source Software - JOSS) have built their own standards and workflows based on the GitHub platform. Similarly, OH communities have started to build evaluation principles for hardware which tend to be more qualitative. Depending on the piece of hardware, it may include different layers of mechanical and/or electronic elements which are analysed according to their information products (bill of materials, technical drawings, parts lists, etc.). The goal is to analyse the completeness of the technical documentation so that replication of the hardware is possible. In order to review this, the technical documentation needs to be prepared and structured according to generally acknowledged standards which sufficiently describe all attributes of the hardware and allow referencing components and parts for the review reporting. Also, widely used original or export formats need to be utilised so that it can be reviewed. The existing prototype is processing this documentation in a wiki form and reviewers can interact with the content of that wiki. We will expand this tool and integrate it in a publication system.

Registration and awareness depend on the use of a metadata model that is used in the targeted community. We want to expand the metadata model drawn on for most data and software publication, i.e. the DataCite model and/or the Schema.org model (https://schema.org/), using the Open Knowhow initiative metadata as a starting point. This would allow for efficient hardware discovery tools, similar to the tools in development for datasets (see https://www.go-fair.org/implementation-networks/overview/discovery/).

We will consider different tooling to provide a long-term archive of the hardware publication. Our choice will depend on the tool the community is employing for documenting their

hardware, the technology used for the evaluation tool and our discussion with the BUA IT infrastructure. It will likely involve making use of tools previously developed for the archive of data and software, as in the integration of GitLab for version-controlled documentation and Dspace for long-term archiving.

Additionally, we will provide an efficient way to choose and apply a licence to the hardware. Similar to the tool provided by creative commons (https://chooser-beta.creativecommons.org/), we will set a list of questions whose response will be used to indicate what licence best matches the will of the hardware developers.

In order to build the foundation of a recognition system, we will prototype a badging system for hardware and their makers using open badges ("Digital Badges | IMS Global Learning Consortium" 2021). Additional tools like continuous integration and banners will also be considered. In particular, we will follow the progress in providing extra recognition for dataset and software, looking especially at tools integrated in researcher's ORCID profiles.

In the implementation we will favour the use of open source software and open, decentralised infrastructures throughout the project. The project will be dockerised to allow for easy installation of the tool. We will also involve the IT and libraries of the three universities early in the project in order to benefit from their expertise. We will also look for partners to deploy our software solution at the end of the testing phase.

Alternatively, a commercial implementation of the created system could be envisaged. Indeed, the organisation of the evaluation (finding reviewers) is a time-consuming task and the publication and archiving of the hardware documentation is not free of charge. We may end up aiding OH communities to build a diamond/platinum open access "journal" for hardware, much like the JOSS.

Use cases

In order to refine the tools and demonstrate the efficiency of our approach, we will use the following relevant hardware pieces from the labs of the partners (among others to be chosen as part of WP1) as use cases and run them through the evaluation and publication process:

- The Airtrack system (HUB, Nashaat et al. 2016), a virtual environment for head-fixed mice was developed in 2016 in the Larkum lab and has been rebuilt several times in the US (Adam Kepec, Dieter Jaeger), in Australia (Lucy Palmer), in Germany (Kremkow) and in the United Kingdom (Andy King). We will analyse the process and especially differences between the five replications and the history of the tool documentation, especially.

- The RoboFish system (FUB, Landgraf et al. 2016) was developed in the Biorobotics Lab and was rebuilt at the HUB (with Prof. Dr. Jens Krause) and the University of Bonn (with Prof. Dr. Gerhard von der Emde). Within the scope of the Electrofish project (https://www.mi.fu-berlin.de/inf/groups/ag-ki/Projects/Elektrofisch/index.html) the RoboFish system is also going to be extended to electrical signals.

- The COSI Measure (https://www.opensourceimaging.org/project/cosi-measure/) was developed by our cooperation partner PTB together with the Open Source Imaging Initiative for community-based development of medical imaging devices (ibid.). Cost-effective open source imaging (COSI) is a collaborative initiative to build an affordable low-field open source magnet resonance scanner. COSI Measure is an open source multi-purpose 3-axis robot for static or dynamic field measurement (electromagnetic, temperature, etc.). It has been

replicated independently at least three times and will serve as an interesting use case at the intersection of automation and the medical field.
Planned cooperation
This project requires knowledge and experience in hardware evaluation (TUB), in scholarly communication and data publication (HUB), as well as hardware and software development (FUB). Our objectives can only be achieved with the expertise of the three labs involved in the project. Each work package will thus be performed in a collaborative manner between the three teams. Nevertheless, a responsible unit was assigned to individual tasks (see work program). The TUB will be responsible for project coordination and the HUB for data management tasks, as well as the international networking in scholarly communication circles. At the same time, the TUB and FUB will be responsible for the cooperation with OH communities and software development. The PTB will participate in the project as a cooperation partner to provide their use cases described in the previous section. Discussions and exchanges between the partners are primordial in this project as each team brings a different expertise necessary for the success of this ambitious project. The visual abstract (visible on the cover page) depicts the drivers that will together set the gear in motion and make open hardware a recognised output of research. The expertise and interest of the three labs will bring the synergies needed to engage this process under the BUA umbrella, while engaging closely with external communities. We have the possibility to link open source hardware initiatives, academic hardware makers and scholarly communication initiatives, in order to expand the scholarly commons towards the inclusion of peer-reviewed hardware. Mr. Robert Mies (TUB), Dr. Julien Colomb (HUB) and Mr. Moritz Maxeiner (FUB) will be working as a team during the whole grant period. Their close cooperation and data sharing will be fostered by using GIN, an online and open source tool bringing GitHub project management solution together with a support for large data. All partners will be asked to share relevant files in the consortium and prepare their documentation to be released and published. If legally possible they will work in the open so that putative partners can follow the progress in real time. Issues in GIN will be used to keep track of the project advances and to assign tasks. To monitor the progress of the project, there will be least bi-weekly meetings where advances, problems will be discussed and decisions taken. A meeting with the whole team will be organised at least every three months. The meeting agenda and minutes will be prepared by the TUB and saved in the GIN repository. A similar (while more condensed) workflow has proven successful for the design and redaction of this application. We will also actively seek to recruit additional collaborators and expertise and continue international networking during the project. We will for instance coordinate our work with the GOSH to create a FORCE11 interest group and/or an RDA working group at the beginning of the project. Furthermore, we will contact and involve the university IT services in the discussion and choice of infrastructure. This will bring additional feedback and visibility to the project.
Data and publication management
This project will be carried out using an open research methodology, where data, results,

discussion and ideas will be shared in an open repository on GIN (gin.g-node.org/) using a standard research folder organization (Colomb et al. 2021). Raw (or anonymised) datasets will be made available with a CC0 licence upon collection, or as soon as legally possible. Data will be curated and its analysis will be executed using reproducible reports in order to facilitate re-use. Upon publication, the whole repository will be archived and published via the GIN platform.

Hardware will be published following the workflow developed in this project under an open source licence for hardware. Software will be published on Zenodo, under an MIT licence.

Intermediary reports will be published on blog platforms specialised in scholarly communication or hardware makers (depending on the topic of the report) under a CC-BY licence. Manuscript will be uploaded in a preprint server before submission to a journal. Following Plan S by Coalition S (see https://www.coalition-s.org/), only gold and diamond open access journals (offering CC-BY licence and copyright retention by the authors and being in the DOAJ index), will be considered as host for our outputs.

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