Final Report: FOSH Literature Review

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Our project was a systematic literature review of Free and Open Source Hardware (FOSH). Since starting to look at the literature on this subject, we have learned many things.

Firstly, the field is relatively new, yet somewhat vast at the same time. The types of hardware we are considering were very limited. There have been two journals that have been started since 2017, and our project will base most of its review. This is good news for our project since it means our review is a systematic review of almost *all* the literature on this subject.

Given the new information, we have refactored and refined some of our research questions. Some questions from the proposal may be beyond the scope of a single paper to be answered, so some may be omitted altogether.

You can see a repository of our project along with a working document **??** that goes over the details here (Not finished).

Additional Key Words and Phrases: Open source design, Open source hardware

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1 INTRODUCTION

1.1 Background and Motivation

The free and open source movement is defined by the following four principles:

> A program is a free software if the program's users have the four essential freedoms:
> - The freedom to run the program as you wish, for any purpose (freedom 0).
> - The freedom to study how the program works, and change it so it does your computing as you wish (freedom 1). Access to the source code is a precondition for this.
> - The freedom to redistribute copies to help your neighbour (freedom 2).
> - The freedom to distribute copies of your modified versions to others (freedom 3). Doing this gives the whole community a chance to benefit from your changes. Access to the source code is a precondition for this.
>
> A program is a free software if it gives users adequately all of these freedoms. Otherwise, it is non-free. While we can distinguish various non-free distribution schemes in terms of how far they fall short of being free, we consider them all equally unethical.

[28].

These four principles have started a movement that has revolutionised intellectual property and specifically technology. We have seen the vast social and technical benefits of this movement. The free and open source movement has democratised access to information and technology: any person has access to the basic principles of [28] on the best software. The movement's technical benefit has been the increase of innovation and collaboration. It is no wonder when neighbours help each other build, we have software like the Linux Kernel, Mozzila Firefox, and many others.

These four principles have been applied to other fields than software. Similar to the free and open source software (FOSS), free and open source hardware (FOSH) is any piece of information that is needed to exercise the four principles as it applies to hardware. These include anything such as design files, blueprints, specifications, documentation, and even software for the building, designing, modifying, distributing, and using hardware. A common example of FOSH is Arduino used for single board microcontrollers in a variety of applications.

FOSH has been growing in interest over the years. This is evident in terms of the increasing number of projects, associations, literature. The Open Hardware Association tracks 2062 FOSH projects to date [1]. It also lists multiple journals that have started since 2017. These include,

- Journal of Open Hardware
- HardwareX
- The Journal of Open Engineering
- Computers, Design and Technologies from MDPI
  - https://www.mdpi.com/journal/computers
  - https://www.mdpi.com/journal/designs
  - https://www.mdpi.com/journal/technologies

The new development FOSH provides researchers an interesting study on the open source movement outside the common FOSH movement. This is the goal of this project.

1.2 Related work

Systematic reviews aim to address a series of research questions by identifying and elucidating existing knowledge gaps, contrasting hypotheses, or broadening the scope of subject matter within a specific area of expertise [10]. The insights gained from systematic

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reviews enable stakeholders, practitioners, and researchers to make informed decisions and strategize future investigations to bridge identified gaps based on the accumulated evidence. Petticrew and Roberts [23] assert that the initial phase in the development of a systematic literature review (SLR) involves determining the necessity of conducting a review on a particular topic.

Annually, approximately 2.5 million new scientific papers are published, necessitating secondary studies that synthesize and systematically organize the knowledge within a specific area. These studies benefit researchers by identifying research gaps and aiding practitioners in understanding the effectiveness of specific methods or technologies.

To the best of our knowledge, this paper is the sole secondary study overviewing the state of art free and open-source hardware(FOSH) . Other related studies include:

1) Saari et al.[25], surveyed multiple network sensor solutions utilizing Raspberry Pi for the Internet of Things;
2) Sullivan and Heffernan [29], who conducted a systematic literature review on robotics construction kits in STEM disciplines
3) Heradio et al. [11] performed a systematic mapping study of OSHW in education, albeit dated;
4) Ariza and Pearce [5] explored low-cost assistive technologies for disabled individuals using OSHW and software.

However, most of these reviews primarily summarize the stages of hardware development and lack exploration into aspects such as licences, community collaboration, and related literature reviews.

1.3 Research question

To comprehend the complexity and diversity of Free and Open Source Hardware (FOSH), it is crucial to explore its various forms, scopes, and applications. Hence, we pose the following research question:

RQA: What are the types, scopes, and applications of FOSH?

Rationale: Understanding the types, scopes, and applications of FOSH will enable researchers, practitioners, and stakeholders to better grasp the potential of FOSH in various domains and enhance its utilization and impact. Answers to the application of FOSH can determine the success or limitations of the movement.

Secondly, to measure the level of freedom as described by the four principles of [28], we ask

RQB: What are the licences of the components of FOSH?

Rationale: Identifying the licenses of FOSH components will help in determining the level of freedom and openness, thus ensuring the compatibility and accessibility of the components across different FOSH projects. The information on licencing could provide answers to the importance practitioners have on the principles, as well as how they are packaging their products.

Thirdly, we would like to understand the collaboration environments of FOSH.

RQC: How do the collaborations of FOSH take place?

Rationale: Exploring the collaboration environments of FOSH projects will provide insights into the interaction dynamics between contributors, fostering better understanding and improvement of communication and cooperation strategies within the FOSH community. Understanding collaboration environments is essential to understanding the social aspect of how people exercise the four principles of freedom defined by [28].

1.4 Significance

The results of this study are significant as they provide insights to understanding the free and open-source movement. They can be used to improve aspects of FOSS or other similar movements both socially and technically.

2 METHODOLOGY

2.1 Literature Review

Our systematic literature review (SLR) adhered to the methodological guidelines and procedural steps established by Gough et al. [10] and Petticrew & Roberts [23], which can be encapsulated as follows:

- 1) Formulation of research questions and a conceptual framework;
- 2) Searching and screening for pertinent literature based on predetermined eligibility criteria
- 3) Coding the literature to align with the conceptual framework
- 4) Employing quality appraisal criteria;
- 5) Synthesizing the selected studies within the context of the conceptual framework or using study codes;
- 6) Interpreting and disseminating the findings.

These steps were executed in conjunction with the PRISMA guidelines provided by [19] to facilitate the various phases of the review process.

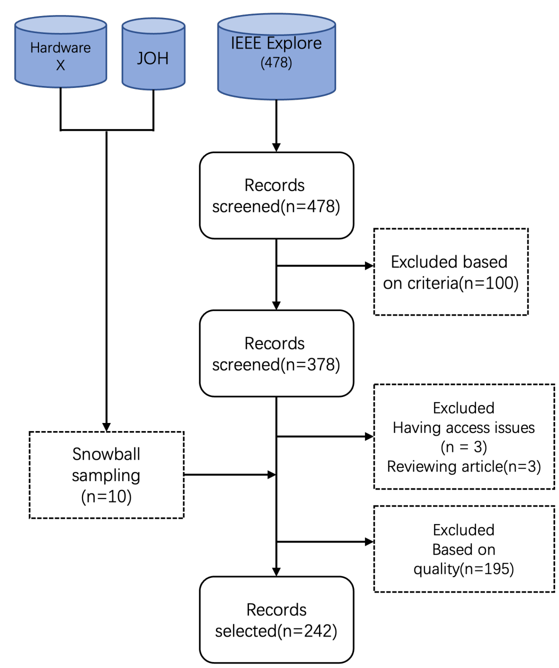

Fig. 1. Systematic Literature Review Process

Figure 1 illustrates the stages of the SLR in accordance with the aforementioned guidelines. To answer the question regarding the collaborative environments, our method is a grey literature review. The qualitative questions posed can be effectively answered by a systematic literature review, as the movement is very young. Most if not all the literature on the subject can be reviewed, along with all the projects listed by the Open Source Hardware Association.

2.1.1 Search Scope. The publications of the FOSH journals were the initial pool of publications for our search. An effective strategy for acquiring a dependable collection of publications is to search through high-quality bibliographic databases [22]. We chose databases that implement a discerning inclusion process, in which in-house editors assess prospective publication venues using factors such as the peer-review system, global diversity of editors and authors, citation influence, and self-citation rates. As a result, we identified the following databases, which have proven successful in prior secondary research: IEEE Explore, ACM library, and Scopus.

2.1.2 Screening And Selection. The search string underwent multiple refinements to maximize the number of relevant studies within the scope of the Systematic Literature Review (SLR). For example, the initial search string included terms such as "open-source hardware" and "open hardware," as demonstrated in block.

```
("Document Title":open source hardware)
OR ("Document Title":opensource)
OR ("Document Title":open-source)
AND ("Abstract":hardware)
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Subsequently, a secondary search string was constructed, incorporating key terms like "community," "state of the art," and "collaboration," which are commonly associated with FOSH applications used in academic and industrial research, as identified in systematic reviews.

This approach yielded a total of 372 records from the aforementioned sources. The records of the retrieved articles were exported to a CSV file to identify duplicates and complete any missing information.

The aforementioned query was executed on April 1st, 2023 and we defined the inclusion and exclusion criteria to filter the extracted publications from the databases. Specifically, the inclusion criteria were as follows:

In a distinct structure, the screening process for the n=478 records commenced with a review of the titles and abstracts. Studies that did not meet the inclusion criteria outlined in Table (3) and were not within the scope of the SLR were eliminated. Following this procedure, n=100 records from the IEEE explore database, as well as JOH and HardwareX journals, were excluded, leaving n=378 articles. The remaining articles were examined for eligibility, and those lacking a DOI, having access issues (n=3), or not being primary research (e.g., literature reviews and surveys) were removed (n=3). Subsequently, each remaining article was assessed based on a quality criterion employing a Likert scale survey, which ranged from 1 to 3, as shown in Table (2). These survey questions were designed with FOSH features and the SLR scope's relevance in mind. All questions carried equal weight, meaning that an article's overall score was determined by the average of these questions' scores. Ultimately, articles with a total average score above 12 were excluded, resulting in n=242 articles, as illustrated in Fig. (1).

Table 1. Inclusion and Exclusion Criteria

I/E	No.	Criteria
I	1	Include publications that addressed at least one of the research questions outlined in this study .
I	2	Include peer-reviewed primary studies that are relevant to FOSH (cross-checking and validation needed for such studies).
I	3	If there are multiple relevant studies that report the same research, then include the longest study only and exclude the rest of them.
E	1	Exclude publications not written in English
E	2	Exclude publications with no accessible full-text
E	3	Exclude tables of contents, editorials, white papers, commentaries, extended abstracts, communications, books, tutorials, non-peer-reviewed papers, and duplicates.
E	4	Exclude brief papers comprising fewer than six pages in single-column format.
E	5	Exclude review articles and secondary studies.
E	6	Exclude papers deemed irrelevant to FOSH based on title, abstract, keywords, introduction, and conclusion, requiring cross-checking and validation.

Table 2. Quality survey to assess the articles in the SLR.

Survey Questions	Range (1-3)
Q1. Does the study describe clear criteria for the selection of the hardware used in the state of art senerio?	(1: agree to 3: disagree)
Q2. Does the study show a method and experiments that allow validating the state of art performance ?	(1: agree to 3: disagree)
Q3. Does the study mention the collaboration or other community related material of the FOSH?	(1: agree to 3: disagree)
Q4. Does the study indicate the scope and limitations of the FOSH developed?	(1: agree to 3: disagree)
Q5. Is the developed hardware application accessible, replicable, and reusable?	(1: agree to 3: disagree)
Q6. Has the study been cited by other authors?	(1: Yes, 3: No)

2.1.3 Snowballing. To expand the selection of investigations included in the SLR, snowballing guidelines provided by Wohlin [33] were utilized to ensure that our study did not overlook any pertinent publications. Upon filtering the initial sample set of publications, the snowballing method expanded the collection by examining their references as well. It is important to note that formal snowballing is an iterative process: during each cycle, new publications are identified, and their references are analyzed in subsequent iterations. However, due to the relatively small number of significant publications found in other sources, we conducted only one iteration, resulting in the addition of n=10 publications from sources beyond the primary database, IEEE. Notably, specialized OSHW journals, such as HardwareX and Journal of Open Hardware (JOH), were incorporated into the search process.

2.1.4 Data Extraction and Analysis. During the data extraction and analysis phase, we employed a clustering technique to categorize the documents based on their textual content. Specifically, we applied the K-means clustering algorithm to group the articles according to the similarity of their titles and abstracts within the TF-IDF feature space, which is a numerical representation of the importance of words in the documents.

To ascertain the optimal number of clusters (k), we examined the elbow method and silhouette scores, which offer insights into the ideal cluster count by taking into account the within-cluster sum of squares and the average silhouette width, respectively. After determining the optimal k value, we implemented the K-means clustering algorithm and allocated each document to its corresponding cluster.

For a better interpretation of the results and a deeper understanding of the themes or topics within each cluster, we extracted the top keywords associated with each cluster. Furthermore, we generated word clouds to visually represent the most prominent keywords within each cluster, which facilitated the identification of prevalent themes and topics. This approach provided valuable insights into the connections between the articles and their potential relevance to the research objectives, while also offering an accessible and engaging means of conveying the information.

2.2 Scripts And API

The Open Source Hardware Association tracks all FOSH projects. It also provides an API that can be used to query information on licensing and collaboration environments.

We used this API to collect all FOSH projects tracked to date. These projects have three pieces with licences; these are hardware, software, and documentation. Additionally, the API was used to collect the websites, and platforms used to store the project. Mostly these platforms are GitHub, and as such the number of forks, comments, issues, contributors are also scraped using the GitHub API.

2.3 Limitations

Despite the application of rigorous protocols for data collection and analysis throughout the systematic literature review, certain limitations were encountered. One of these limitations pertains to the selection of databases used in the search process. The chosen database was selected due to its extensive collection of FOSH-related studies and its ability to provide a substantial corpus of designs for analysis under the PRISMA guidelines. Nevertheless, future studies could benefit from including more comprehensive databases such as Scopus, Web of Science(WoS), ACM Guide to Computing Literature, and Google Scholar to further supplement and expand upon the findings of this research.

Second limitation of this study arises from the selected timeframe (2017-2022). This period was chosen because it encompasses a substantial portion of the relevant designs and aligns with the state-of-the-art FOSH technologies, such as NVidia Jetson, Arduino, Raspberry Pi. However, it is important to acknowledge that some significant studies may fall outside of this timeframe or may have garnered citations after the search date, potentially impacting the comprehensiveness of the review.

A third limitation pertains to the search strings. Standardized terms, such as "open-source hardware," were employed; however, this may have led to the exclusion of other terms or more specific terminology (e.g., collaboration hardware, open innovation) that researchers use to describe their developments or target audiences in the SLR process. Limitation can also stem from the exclusion of gray literature, such as white papers, preprints, or working papers, as well as documents not written in English. This constraint is inherent in the features and procedures of an SLR, limiting the range of document sources that researchers can analyze and potentially affecting the comprehensiveness of the findings.

A fourth limitation arises from the time constraints associated with this project. Although our initial plan was to search all available databases for FOSH, our results primarily came from the IEEE database. We conjecture that platforms such as GitHub repositories may also host state-of-the-art open-source hardware projects, but due to time restrictions, we were unable to include them in our search. This limitation may impact the comprehensiveness and generalizability of our findings.

A fifth limitation pertains to the data analysis phase. Although we employed a clustering technique, more advanced professional tools could have been utilized for a comprehensive bibliometric analysis. Examples of such tools include, VOSViewer [31], and Crossref REST API [13], which are designed for network data analysis, focusing on items and clusters while providing overall functions to create and visualize maps. Some text analytics tool like Leximancer [27] that can analyze the contents of document collections and visualize their trends in concept maps. The use of these advanced tools might have yielded additional insights and a more in-depth understanding of the relationships and patterns within the data.

Additionally, the use of the K-means clustering algorithm in our data analysis phase has its inherent limitations. K-means clustering assumes that the clusters are spherical and equally sized, which might not always be the case for real-world datasets. Moreover, it is sensitive to the initial placement of cluster centroids and may converge to a local optimum. While we made efforts to determine the optimal number of clusters using methods like the elbow method and silhouette scores, alternative clustering algorithms, such as hierarchical clustering or DBSCAN, could potentially provide different perspectives on the structure of the data.

3 RESULTS

The comprehensive results of our study can be accessed via the subsequent GitHub Repository.

FOSH is a new way of designing and building hardware that's become popular in many areas since it is open for innovation and can be democratically beneficial to the community.

3.1 Clustering Result

Considering the clustering result of k-means, table() shows the top keywords associated with each cluster

Cluster	Top Keywords
0	monitoring, system, platform, opensource, lowcost, environment, using, wearable, robot, acoustic
1	network, 5g, open, nfv, software, source, networks, radio, service, sdr
2	design,ics, opensource, communication, smart, open, research, hardware, system, community
3	open, system, source, opensource, hardware, data, software, control, design, platform
4	opensource, design, fpga, hardware, framework, learning, fpgas, neural, using, performance

Table 3. Top keywords for each cluster

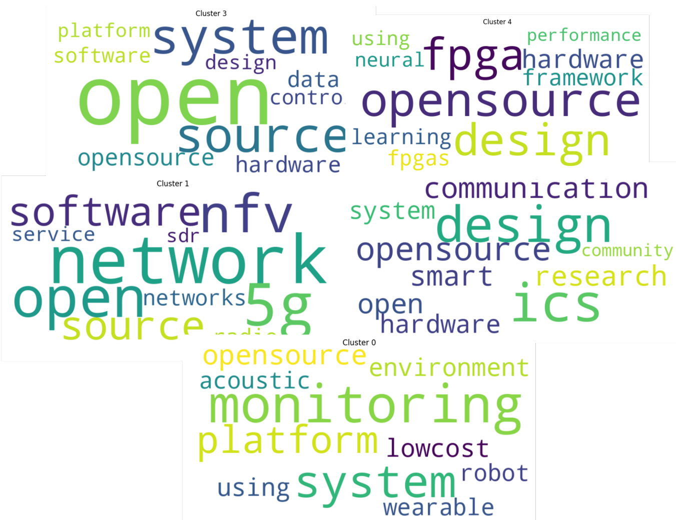

Fig. 2. Word cloud based on the keywords in each cluster.

The development of keywords from 2017 to 2022 can be observed in Fig.(2). Clusters indicate a variety of trends and technological advancements in the field of open-source hardware. In Cluster 0, the focus is on monitoring systems, platforms, and wearable robotics, demonstrating a growing interest in environmental and personal monitoring applications. Cluster 1 highlights the role of network technologies, with 5G, NFV, and SDR being prominent keywords, showcasing the integration of open-source hardware in communication networks and radio systems.

Cluster 2 emphasizes the importance of design and community in the open-source hardware landscape, with a focus on smart communication systems and integrated circuits. This suggests a strong emphasis on collaboration and research in the development of open-source hardware technologies.

Cluster 3 showcases the interplay between open-source hardware and software, with keywords such as data, control, and platform indicating a broad range of applications and integrations with other technologies.

Finally, Cluster 4 demonstrates the growing relevance of FPGA technology, machine learning, and neural networks in the field of open-source hardware. This indicates that researchers and developers are exploring the potential of open-source hardware to enhance the performance and capabilities of cutting-edge technologies in artificial intelligence and other advanced domains.

Based on the result of the systematic literature review, we can divide the perspective of FOSH in the following categories: electronics and computing, robotics and automation, and education and research.

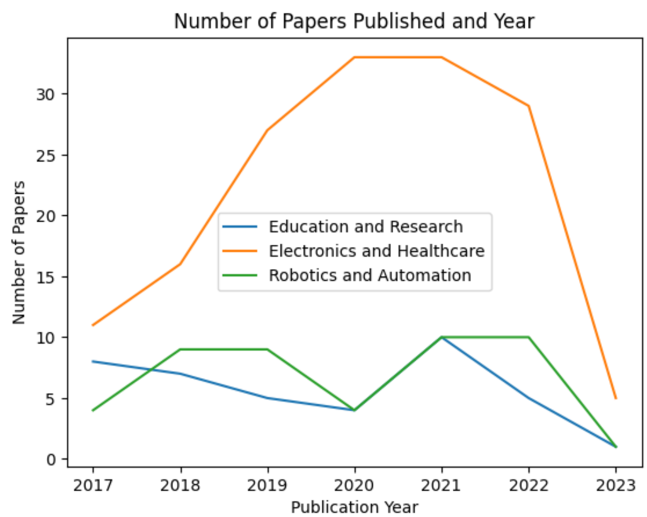

Fig. 3. Number of papers published in each categories every year

The above figure shows the number of papers published in each year for three different topics, which will be detail explained later. Each topic is represented by a different line color, with a legend indicating which line corresponds to which topic. Note that among the approximately 200 papers, we observed that the majority of papers falls into category "Electronics and Healthcare" compared with the other two. This topic also reaches its high peak between 2020 and 2021, while the other two categories doesn't have a significant difference in number of papers published every year.

3.2 Education and Research

The proliferation of open-source hardware has led to its increasing adoption in educational institutions, ranging from K-12 to graduate programs.[16] This trend can be attributed to the wide applicability of open-source hardware in diverse fields such as electronics[20], computer science, digital media design[8], robotics[32], and automated vehicles[18]. Taking open-source hardware into courses can provide students with a more comprehensive understanding of the relevant concepts and facilitate hands-on learning experiences.[8]

Arduino, and Arduino-based platforms, are the most prevalent open-source hardware utilized in schools. These tools enable the design of laboratory exercises that target the acquisition of knowledge and skills related to microcontrollers[24], microprocessors[20], embedded systems[6], mobile communication networks[14], optical wireless communications[2], and chip design[3]. The versatility and accessibility of open-source hardware make them ideal for fostering a deeper understanding of the basic principles.

What's more, the appearance of new open-source hardware platforms such as the power electronics didactic platform[12], the "ball-on-beam didactic device"[30], the robotic manipulation platform[7], and the development of the front-end for the FPGA-based platform[6] has further facilitated the teaching and learning of the hardware. In addition to the cost-saving benefits, these open-source hardware tools aim to inspire students to contribute to the existing open-source hardware ecosystem. As highlighted by V. V. Rankovska et al, the high cost of scientific tools will impede the pace of technological progress. [24] Thus, the incorporation of open-source hardware in education can have benefits both in reducing cost and activating the development of the hardware.

3.3 Electronics and Healthcare

Some of the most popular and successful hardware are open-sourced, such as Risc-V and Arduino. These are free for modification, which is also commonly introduced and extended too various new products. For example, Mlakić1 et al. proposed a measurement device implemented based on Arduino [17]. This can be further used to make own IED capable of IoT and smart grid symbiosis. Arduino can also be combined with various products to realize human-computer interaction. One example would be Yuning Fan's programming language-based interactive device, which is an interface designed not only for the potential benefit technologically but also to educate children at the same time [9]. As mentioned in the previous paragraph, education is a major field that FOSH is contributing to an strongly impacted in today's community. One major reason for any implementation of electronic or computing products is to reduce the cost of the current solution. Noted the vital and complex role of the medical realm, some researches focus on different fields of this branch. For example, the ultrasound test bench demonstrated by Pashaei et al. can be further extended to other devices [21]. The key sellout of this product is that it's always in demand for medical equipment, where making the design open-sourced would greatly benefit the whole medical community. In addition, given the limitation of availability of affordable medical equipment to treat chronic conditions, Dorin et al. explore the Loop Open-source Artificial Pancreas (APS) [**?**]. There are similar designs that add convenience for health-related measurement devices such as OpenSenseRT which is also low-cost and extendable, and the robotic platform to enable dexterous procedures within CT scanners which is practically a robot hand that allows physicians to localize tumours quickly [26]. Robots are another major application area in the FOSH community, which will be further explored in the next paragraph.

3.4 Robotics and Automation

In general, robots are often created to either complete tasks that humans are unable to or to increase productivity. VIKTOR III is an open source robot to improve the farming production quality by not only "empower[ing] individuals to grow their own food [but also] serve[ing] as a platform for robotics education". This also falls into the category of the benefit of open-source products can bring to the field of education. By improving on the current older invention, an open-sourced robot named FarmBot, VIKTOR III can be built only using 1/6 of its cost but with completely the same feature. It also uses state-of-art machine learning technology deep learning that provides a higher plant detection accuracy. The inventors also suggested that it can help astronauts harvest in space. By doing so, it provides a blueprint for future design and study purposes. There are many products that share the same goal, such as the Yale OpenHand Project, which focus on improving the design process and producing various options for the researchers to adopt on [15]. The inventor of WoodenHaptics also agrees with the importance of innovation, which is why they published the blueprint for this design in order to "Lowering the barriers to inspire experimentation" [34]. As a realm that is constantly been developed and updated by new technologies, they believe the ultimate future goal for any open-source robot is "identifying willing end users who will put their own design modifications online, thereby allowing progress in the research community to move even faster" [34]. In fact, this concept of republishing the modified product is also widely and strongly agreed upon by many researchers, which leads to the invention of ROS[4] (Robot Operating System) that allows people to communicate. The aspect of FOSH communities will be further discussed later.

3.5 Licences

There are three pieces of an FOSH that has a licence, the hardware, the software, and the documentation. The licences can be seen in the tables 4, 5, and 6. The hardware are predominately packaged with a CERN or a derivative of this licence. The CERN licence also appears in the software and documentation, but it is not the main type. Software is packaged with the common MIT licence and the documentation has a common public licence.

4 DISCUSSION

As discussed above, FOSH itself is likely to be characterized by continued innovation and expansion, as well as a focus on developing more specialized and adaptable FOSH electronic platforms. With the continued development of FOSH platforms like Linux and Arduino. FOSH also has the potential to positively and significantly impact healthcare from many perspectives. In the future, we believe there will be continued development of affordable and accessible FOSH medical devices, aiming to reduce the cost to meet the needs of low-resource environments. In addition, rigorous quality standards and certification processes for FOSH medical devices will be established, which can further build consumer trust and confidence in these products. Given that operational products such as robot hands or detectors are not fully tested and matured yet, it is necessary for FOSH communities and healthcare professionals to collaborate and

Licence	Number
Other	1077
CERN	669
CERN-OHL-S-2.0	65
CERN-OHL-P-2.0	37
CERN-OHL-W-2.0	22
CERN-OHL-1.2	27
GPL	4
GPL-3.0-or-later	11
GPL-3.0-only	4
CC0-1.0	2
CC-BY-SA-4.0	34
CC-BY-4.0	11
TAPR	82
Solderpad	16
None	

Table 4. Hardware Licences

Licence	Number
No software	394
MIT	1101
GPL	270
GPL-3.0-or-later	32
GPL-3.0-only	13
LGPL	34
CC-BY-SA-4.0	8
CC-BY-4.0	4
CC0-1.0	
CC-BY-SA-4.0	8
CERN-OHL-P-2.0	1
CERN-OHL-W-2.0	3
CERN-OHL-S-2.0	13
Other	152
Apache	34
None	1
Mozilla	1

Table 5. Software Licences

ensure their safety and effectiveness. This will effectively promote the integration of FOSH into healthcare systems.

As for the field of robotics and automation, there will be continued development of more advanced and sophisticated FOSH devices, including the most state-of-the-art integration of artificial intelligence and machine learning technologies, which will be continuously updated as technology advances.

In the educational context, the increasing adoption of open-source hardware in academic institutions required that current contributors and developers of open-source hardware consider putting more attention to the FOSH documentation and user interfaces. By making these resources more accessible and user-friendly, novice users, such as students, can more readily engage with the material and acquire foundational knowledge of open-source hardware principles. This

Licence	Number
CC BY-SA	1541
CC-BY-4.0	36
CC BY	125
CC-BY-SA-4.0	51
CC 0	19
CC0-1.0	6
GPL	7
GPL-3.0-or-later	11
GPL-3.0-only	3
CERN-OHL-P-2.0	5
CERN-OHL-S-2.0	24
CERN-OHL-W-2.0	6
Other	227
None	

Table 6. Documentation Licences

approach will ultimately foster interest in hardware development and facilitate the learning process for those new to the field.

Additionally, in order to make the FOSH community more collaborative, we also encourage hardware contributors to follow the principles from industry and academia which will motivate further open-source hardware developers' participation.

5 CONCLUSION

5.1 RQA: What are the types, scopes, and applications in the FOSH community?

5.1.1 types. The FOSH community includes current popular open-source hardware platforms like Arduino and Raspberry Pi, as well as 3D printing technology and software. There are also electronic components. In addition, robotics automation technology, medical devices and educational resource platforms are also the major types of FOSH.

5.1.2 scopes. The FOSH community encompasses a wide range of scopes, from small-scale side projects to large-scale industrial projects. There are also research and development projects in academic and scientific settings. Some of the community-driven projects are also aimed at addressing social or environmental challenges.

5.1.3 Application. The FOSH community has a diverse set of applications, including the ones we mentioned above which are already divided into three categories. There is education at all levels from K-12 to higher education and vocational training, healthcare including medical devices and equipment, environmental monitoring and conservation, robotics and automation for industrial, agricultural, and domestic applications, scientific research and development including physics, chemistry, and biology, personal or community use small-scale project, and social and humanitarian projects aimed at addressing societal or environmental challenges.

5.2 RQB:

5.3 How do the collaborations of FOSH take place?

Based on our results, there are many available platforms with different focuses for FOSH enthusiasts and practitioners to connect and collaborate online. These forums provide a space for sharing knowledge, troubleshooting technical issues, and collaborating on new projects.

In addressing our third research question, "How do the collaborations of FOSH take place?", we have analyzed the literature and identified several key factors that contribute to successful collaboration in the realm of open-source hardware:

- Innovation Climate: Our analysis revealed that a conducive environment is crucial for fostering collaboration in open-source hardware. Approximately 82% of collaborations were found to occur in makerspaces, such as campus organizations and innovation engineering communities. The atmosphere of mutual respect and effective communication tools within these spaces encourages collaborative efforts.
- Benefit Motivation: The majority of open-source hardware collaborations are driven by a clear understanding of the potential benefits. Collaborations often form to reduce costs, for strategic and economic reasons, or to leverage the diverse motivations of community members. Voluntariness is a core concept in these collaborations, as communities cannot be artificially created or maintained.
- Corporate Involvement: Our findings indicate that 63% of research results in open-source hardware collaborations are produced with the involvement of companies. We speculate that this is due to the ability of companies to facilitate the production of deliverables, guarantee security, and provide marketing, production, and sales resources. These factors contribute to the growth of open-source hardware communities and the proliferation of their work.

- Guided by Clear Hardware Development Principles: Successful open-source hardware collaborations are typically guided by well-defined hardware development principles, which help to ensure consistency and quality in the projects undertaken by the community.

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to be finished

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