Final Report: FOSH Literature Review

ALI RAEISDANAEI, University of Toronto, Canada
JINGYUE ZHANG, University of Toronto, Canada
TIANTIAN LIN, University of Toronto, Canada
ZIQIAN QIU, University of Toronto, Canada

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.

[8].

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 [8] 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 2057 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 [2]. The insights gained from systematic

Authors' addresses: Ali Raeisdanaei, University of Toronto, Canada; Jingyue Zhang, University of Toronto, Canada; Tiantian Lin, University of Toronto, Canada; Ziqian Qiu, University of Toronto, Canada.

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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 [6] 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.[7], surveyed multiple network sensor solutions utilizing Raspberry Pi for the Internet of Things;
2) Sullivan and Heffernan [9], who conducted a systematic literature review on robotics construction kits in STEM disciplines
3) Heradio et al. [3] performed a systematic mapping study of OSHW in education, albeit dated;
4) Ariza and Pearce 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.

Secondly, to measure the level of freedom as described by the four principles of [8], we ask

RQB: What are the licences of the components of FOSH in each type?

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.

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.

1.4 Significance

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

Answers to the application of FOSH can determine the success or limitations of the movement. The information on licencing could provide answers to the importance practitioners have on the principles, as well as how they are packaging their products. Understanding collaboration environments is essential to understanding the social aspect of how people exercise the four principles of freedom defined by [8].

2 METHODOLOGY

2.1 Literature Review

Our systematic literature review (SLR) adhered to the methodological guidelines and procedural steps established by Gough et al. [2] and Petticrew & Roberts [6], 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 [4] to facilitate the various phases of the 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.* (image of the search procedure here)

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 [5]. 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.

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("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:

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.

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 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 [10] 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

2.3 Limitations

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. 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.

3.1 Education and Research

3.2 Electronics and Computing

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.

3.3 Robotics and Automation

In general, robots are often created to either complete tasks that human is unable to, or to increase the 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 platform for robotics education". This also falls into the category of the benefit of open source product can bring to the field of education. By improving on the current older invention, an open-sourced robot named FarmBot, VIKTOR III can be build only using 1/6 of its cost but with completely same feature. It also uses the 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 produces that share the same goal, such as the Yale OpenHand Project, which focus on improving the design process and produce various options for the researchers to adopt on. 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". 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". In fact, this concept of republishing the modified product is also widley and strongly agreed by many researchers, which leads to the invention of ROS (Robot Operating System) that allows people to communicate. The aspect of FOSH communities will be further discussed later.

4 DISCUSSION

Based on the result, Discuss the potential future developments, opportunities, and challenges that FOSH is facing as well as identify the fields where we could focus more attention on FOSH.

5 CONCLUSION

Conclude the result we found and answer the research questions.

ACKNOWLEDGMENTS

to be finished

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