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Participation of women in Open Source Software (OSS) is very unbalanced, despite various efforts to improve diversity. This is concerning not only because women do not get the chance of career and skill developments afforded by OSS, but also because OSS projects suffer from a lack of diversity of thoughts because of a lack of diversity in their projects. Studies that characterize women's participation and investigate how to attract and retain women are spread across multiple fields, including information systems, software engineering, and social science. This paper systematically maps, aggregates, and synthesizes the state-of-the-art on women's participation in Open Source Software. It focuses on women's representation and the demographics of women who contribute to OSS, how they contribute, the acceptance rates of their contributions, their motivations and challenges, and strategies employed by communities to attract and retain women. We identified 51 articles (published between 2005 and 2021) that investigate women's participation in OSS. According to the literature, women represent about 9.8% of OSS contributors; most of them are recent contributors, 20-37 years old, devote less than 5h/week to OSS, and make both non-code and code contributions. Only 5% of projects have women as core developers, and women author less than 5% of pull-requests but have similar or even higher rates of merge acceptance than men. Besides learning new skills and altruism, reciprocity and kinship are motivations especially relevant for women, but can leave if they are not compensated for their contributions. Women's challenges are mainly social, including lack of peer parity and non-inclusive communication from a toxic culture. The literature reports ten strategies, which were mapped to six of the seven challenges. Based on these results, we provide guidelines for future research and practice.

 $CCS \ Concepts: \bullet \ Software \ and \ its \ engineering \rightarrow \ Software \ evolution; \bullet \ Human-centered \ computing \rightarrow \ Open \ source \ software; \bullet \ Social \ and \ professional \ topics \rightarrow \ Women.$

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1 INTRODUCTION

The effects of gender¹ diversity in OSS projects has gained increasing attention from practitioners and researchers [9, 15, 29, 71, 88, 93]. Gender diversity has a positive effect on productivity as it brings different perspectives together, improving outcomes [88], problem-solving capacity, and leading to a healthier work environment [24]. A gender-diverse team has been shown to increase innovation and productivity in software engineering [61, 83, 88].

However, although open source software (OSS) organizations have been taking actions to increase gender diversity and place more women in management positions, the numbers are still low. Women represent only 5.2% of contributors in Apache Software Foundation [73] and 9.9% in Linux kernel [7], two of the largest and best-known OSS communities. Moreover, women represent only 9% of GitHub users [89].

Researchers have been trying to understand the low representation rate of women in OSS, as well as to learn more about their challenges and the strategies that can be adopted to attract and retain this underrepresented population. Existing research suggests that gender bias and sexist behavior pervades OSS [32, 59]. Women reported that feel frustrated when they are the only woman on a development team and when their input is not requested, despite their competence in certain areas of the project [51]. While OSS projects idealize a strict meritocracy in which quality speaks for itself [27], there are several biases that undermine women, who feel their quality is not able to speak for itself and report experiencing the "impostor syndrome" [88]. Gender biases can represent a "glass floor" and a persistent barrier to entry [54, 63]. To avoid negative bias, some women hide their gender by using neutral aliases [51, 87].

Although there are many published scientific studies investigating women's participation in Open Source Software, the findings are scattered in multiple fields and venues, and the results are disconnected from one another. Summarizing and aggregating existing research can help communities fully comprehend women's participation in OSS to define proper mechanisms to increase the number of women contributors and produce new knowledge by connecting previously dissociated research. Therefore, the purpose of this study is as follows:

Purpose. To review, summarize, and synthesize the current state of research on women's participation in Open Source Software.

Through a systematic mapping of the literature including database search, backward and forward snowballing, and input from prolific authors, we selected and retrieved information from 51 primary studies published between 2000 and 2021. Our contributions include identifying: the frequency of women's participation, the characteristics of the women who contribute to OSS, the ways women contribute and the acceptance rates of their contributions, their motivations to participate, the challenges they face as OSS contributors, and the strategies OSS communities can employ to help attract and retain women.

2 RESEARCH METHOD

We performed a systematic mapping of the literature (SML) approach because we expected existing research to be fragmented and not follow common terminology or use established theoretical concepts. The systematic mapping of the literature is suitable in such circumstances because it maps the available evidence [64, 65], categorizing and aggregating knowledge dispersed across disconnected studies. This section details our method, which is based on established guidelines [47, 65].

¹In this study, we use the term "gender" as a socially constructed concept [13] where gender identification, display, and performance might or might not align with the sex assigned at birth. To reflect this social concept of gender, in this paper, we use the term "women" and "men" as a shorthand for people who self-identify as such.

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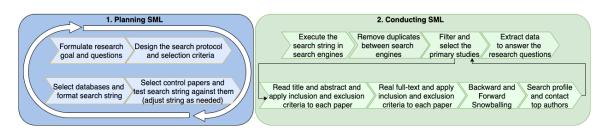


Fig. 1. Steps and phases of Systematic Mapping, adapted from [46]

Fig 1 depicts the steps and phases of our research method. We started by PLANNING THE SML. Three researchers had four meetings to formulate research goals and questions, elaborate the search protocol, define the inclusion and exclusion criteria, and test the search protocol. We piloted the search in Google Scholar and selected four control papers, then executed the search string again and validated that the control papers could be retrieved. We then moved to the second stage of CONDUCTING SML, in which we executed the search string in the selected databases, conducted backward and forward snowballing, contacted the most prolific authors, applied the inclusion and exclusion criteria to filter the studies, and extracted data to answer the research question.

2.1 Planning the SML

In the planning phase, we formulated the search protocol, selection criteria, databases, and search string. We also defined control papers and piloted the study.

2.1.1 *Research Goals.* To understand women's participation in OSS projects, we formulated the following research question: *"How has participation by women in OSS characterized in the literature?"*.

When analyzing the selected primary papers, we categorized the participation of women in OSS from 7 different perspectives:

1. Representation of women in OSS projects The literature presents different statistics for women's representation in OSS, which were measured in different ways, at different moments, and considering different set of projects. We aim to aggregate the results, providing a more comprehensive view of the phenomenon. Linking data obtained from different sources may provide researchers with an expanded view of the phenomenon under study, prompting new insights and allowing for further discoveries [69]. Additionally, analyzing women's representation at different time periods can help us understand the evolution of gender imbalance.

2. Demographics of women contributors to OSS Understanding the characteristics (e.g., education level, age, geolocation, tenure) of women who contribute to OSS projects can help communities and researchers to refine their strategies to attract profiles of women who are still not participating and retain women who currently contribute to OSS.

3. Types of contributions that women make in OSS projects The OSS landscape has changed since the early 2000s to include the participation of ever more people and companies. Project-centric roles are becoming more established, and OSS projects increasingly include community-centric roles, which relate to areas beyond programming [85]. Understanding how women contribute to OSS projects can help attract both code developers as well as those interested being part of OSS via non code-centric roles.

4. Acceptance rate of women's contributions in OSS projects Anecdotes about gender bias appear across the literature [48, 82], and women have been reported to feel that such biases are to blame for their contributions' comparatively low acceptance rate [14]. We aim to aggregate the scientific evidence about gender bias and understand what impact such biases have on the acceptance of women's contributions. Understanding the biases can help steer future research and community policies and can inform current and future contributors.

5. Motivations that drive women to participate in OSS projects Research has shown that women are more motivated to use technology to accomplish a goal rather than for fun [10]. For the past 20 years, much academic work has theorized about and empirically examined OSS contributors' motivations. Retrieving and consolidating women's motivations from the existing studies is relevant to communities seeking to recruit and retain women. Proper management of motivation and satisfaction helps software organizations achieve higher productivity levels and avoid turnover, budget overflows, and delivery delays [6, 18, 30].

6. Challenges faced by women when contributing to OSS projects Previous work investigated challenges faced by OSS contributors who are mentors and newcomers [4, 54, 79, 80]. Some of them report gender bias as a challenge [4], and others report barriers faced by women [22]. Understanding the nuances of women's challenges to contribute to OSS can help communities plan strategies to mitigate these challenges and thereby attract and retain more women.

7. Strategies to increase women's participation in OSS projects Strategy proposals are scattered and rarely widely adopted. OSS communities need a concise view of the different types of actions to select the ones that are viable and appropriate for their needs and for the challenges they face.

2.1.2 Search Protocol and Selection Criteria. We designed a study protocol to conduct a systematic mapping of the literature, which includes paper collection (database search, snowballing, and top-authors validation) and filtering. The filtering was applied according to the following Inclusion (IC) and Exclusion (EC) criteria.

- IC1. The paper explicitly reports women's degree of participation, characteristics, performed activities, motivations, challenges or barriers faced, or strategies used to attract or retain women as OSS contributors.
- EC1. The publication is just an abstract
- EC2. The publication is not written in English
- EC3. The publication is a copy or an older version of another article already considered
- EC4. The publication is not a peer reviewed paper
- EC5. The publication is a doctoral/master's dissertation, research plan, short paper, or report thereof
- EC6. It was not possible to access the complete work.

2.1.3 Databases and Search String. We used a hybrid strategy [56] to collect primary studies, including database search (IEEE Xplore, Scopus, the ACM Digital Library and Scopus) [65], snowballing, and contact with the most prolific authors. The selected databases are suggested by Kitchenham and Charters [46] to conduct secondary reviews on computer science and software engineering topics, and in our experience provide good coverage. Similar to related work [17, 25, 52, 58], we limited the search to title, abstract, and keywords. Table 1 provides the search string used for each database.

The first part of the search string (before the AND) aims to limit the results to studies about women or the diversity and heterogeneity they can represent. The second part of the search string (after the AND) seeks to limit results to Open Source Software. All searches were completed on November 15, 2020.

As we depicted in Table 1, to avoid missing studies that do not directly mention the terms "women" or "female" in the title, abstract, or keywords, we included in the search string more generic terms such as "diversity" and "gender", understanding that diversity can include many other aspects (e.g. culture, age, tenure) and that gender can refer to genders beyond our focus on women.

2.1.4 *Control Papers and Piloting.* Before searching the selected databases, we conducted exploratory searches using Google Scholar to refine the inclusion and exclusion criteria, the research question, synonyms for the search string, and the information extraction template. From that exploratory search, based on our experience we selected four well-known, relevant studies to act as control papers [14, 70, 82, 87]. In our pilot studies to test the protocol, all four control papers were found.

Database	Search String	Results
Scopus	TITLE-ABS-KEY((woman OR women OR female OR gender OR diversity OR "heterogeneous team")	1067
	AND ("open source" OR "open-source" OR "free software" OR foss OR floss* OR oss))	1007
IEEE	("All Metadata":woman OR "All Metadata": women OR "All Metadata": diversity OR	
	"All Metadata": female OR "All Metadata": "heterogeneous team" OR "All Metadata": gender)	
	AND ("All Metadata":"open source" OR "All Metadata":"open-source"	350
	OR "All Metadata": "free software" OR "All Metadata": OSS	
	OR "All Metadata": FOSS OR "All Metadata": FLOSS*)	
Companday	(((((woman OR women OR female OR gender OR diversity OR "heterogeneous team")	100
Compendex	AND ("open source" OR "open-source" OR "free software" OR foss OR floss* OR oss))))	100
-	Title:(((woman OR women OR female OR gender OR diversity OR "heterogeneous team")	
ACM	AND ("open source" OR "open-source" OR "free software" OR foss OR floss* OR oss)))	
	OR Abstract:(((woman OR women OR gender OR diversity)	879
	AND ("open source" OR "open-source" OR "free software" OR foss OR floss* OR oss)))	019
	OR Keyword:(((woman OR women OR gender OR diversity)	
	AND ("open source" OR "open-source" OR "free software" OR foss OR floss* OR oss)))	

2.2 Conducting the SML

We executed the research protocol, summarized in Fig.1), which comprised the following six steps to execute the search string in selected databases, remove duplicates between databases using manual de-duplication, read and filter the papers applying IC and EC, execute snowballing, and contact the most prolific authors to find additional studies.

Step1: Executing Search. In November 2020, we performed the search on the selected search databases and found 2,396 papers. Fig. 1 shows the number of papers selected in each step of the selection process. We refer to the selected primary studies with 'PS' (e.g., (PS1)) to distinguish them from citations to other references (e.g., [1]).

Step2: Remove Duplicates. We used a spreadsheet to store and organize the retrieved papers, and we ordered the papers by title and manually removed 482 duplicates, avoiding automatic removal.

Step3-4: Select Primary Studies. Selection of papers followed the guidelines proposed by Kitchenham and Charters [46] and Petersen et al. [65] using the steps shown in Fig.1. In the first step, we analyzed only the paper's title and abstract, consulting the entire text only when necessary to reach a confident judgment. In the second step, we filtered the papers considering the full-text reading. In both filters, papers were included to match the inclusion criteria or excluded if they fit any exclusion criteria.

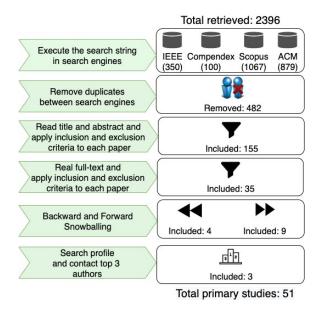


Fig. 2. Steps to Filter and Select the Primary Studies

Step5: Backward and Forward Snowballing: For Backward Snowballing, we conducted a single-step snowballing sampling, checking the papers' references and looking for additional relevant papers. This step resulted in four additional primary studies. For Forward Snowballing, we also conducted a single-step sampling, checking what other papers cited the selected papers. This step resulted in nine additional primary studies.

Step6: Contact prolific authors. We reviewed the publication records and contacted the top 3 most prolific authors, who are arguably specialists in the field. We searched for the Google Scholar profile and personal website of these authors and sent emails to them showing the list of primary papers and asking if they suggest others that we missed and should be included. This step resulted in three additional primary studies.

2.3 Extracting and Analyzing Data

We extracted quantitative data from the papers to analyze what the literature had presented about women's representation in OSS projects and the rate of acceptance of women's contributions. In order to analyze women's representation in OSS projects, we pulled the percentage of women and how the study measured women's participation. We then grouped the findings according to the data source (e.g., mined from software repositories and mailing lists, surveys). In order to analyze the rate of acceptance of women's contributions in OSS projects, we extracted findings about the reported acceptance rate of contributions made by women to OSS projects.

We qualitatively analyzed the papers and inductively applied open coding to understand what is being reported by literature about the demographics of women who contribute to OSS, the types of contributions they make, their motivations, challenges and strategies. For types of contributions and motivations, the coding approach was informed by previous work. To answer types of contributions, we followed the classification defined by Trinkenreich et al. [85], which categorizes coders and non-coders, and project-centric and community-centric roles. For motivations, we used the theoretical framework of OSS motivations proposed by Von Krogh et al.[90], which is a comprehensive investigation Manuscript submitted to ACM

Table 2. The categories of data to explain women's participation in OSS and the respective primary studies that provide data to answer them

Categories of Data - Women's Participation	Primary Studies
1. Representation of women in OSS projects	[PS2, PS3, PS4, PS5, PS9, PS12, PS16, PS17,
	PS21, PS43, PS44, PS46, PS49, PS51]
2. Demographics of women contributors to OSS	[PS1, PS2, PS3, PS4, PS5, PS6, PS7, PS8,
	PS16, PS28, PS45, PS46]
3. Types of contributions that women make in OSS projects	[PS2, PS4, PS5, PS6, PS9, PS10, PS11, PS12,
	PS13, PS14, PS15, PS45, PS46]
4. Rate of acceptance of women's contributions in OSS projects	[PS4, PS6, PS10, PS14]
5. The motivations that drive women to participate in OSS projects	[PS5, PS16, PS18, PS19, PS50, PS51]
6. The challenges faced by women when contributing to OSS projects	[PS13, PS18, PS20, PS21, PS22, PS23, PS24,
	PS25, PS26, PS27, PS28]
7. The strategies been proposed for OSS communities to increase	[PS3, PS6, PS8, PS9, PS12, PS16, PS23, PS24,
women's participation in OSS projects	PS25, PS26, PS27, PS28, PS29, PS30, PS31,
	PS32, PS33, PS34, PS35, PS36, PS37, PS38,
	PS39, PS40, PS41, PS42, PS47, PS48]
	[1009, 1040, 1041, 1042, 1047, 1046]

that aggregates motivation factors found in 40 primary studies published since 2009. The authors grouped the OSS motivation factors in ten main categories, namely, *Ideology, Altruism, Kinship, Fun, Reputation, Reciprocity, Learning, Own-Use, Career*, and *Pay.*

For challenges and strategies, we built post-formed codes and as the analysis progressed associated them with respective parts of the studies' text. Three of the authors conducted three card sorting sessions [78] and discussed the codes and categorization until reaching consensus about the meaning of and relationships among the codes.

3 CHARACTERIZING THE STUDIES

In the following we present some data about the primary studies (e.g., where they were found, when they were published, and who published them).

3.1 Where were studies published?

Fig. 3 shows the distribution of the 35 papers selected from the search engines. The Compendex digital database search did not return any new publications, only duplicated ones.

3.2 When were the studies published?

Fig. 4 shows the number of primary studies published per year. The earliest paper was published in 2000. There were up to six papers per year until 2019, after which we saw a noticeable peak. We included one paper from 2021 through forward snowballing, but decided to not include it in Fig. 4.

3.3 Who has published the studies?

We ranked all 118 authors by the number of publications in the sample to investigate the most prolific authors. Among them, 95 authors had one paper; 17 authors had two papers; five authors had three papers; two authors had four papers; Manuscript submitted to ACM

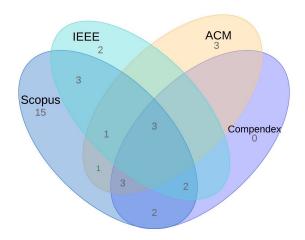
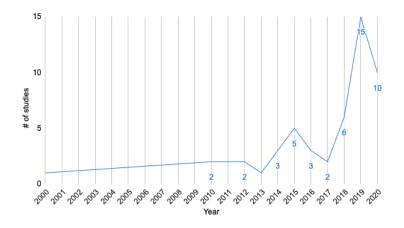
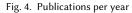


Fig. 3. Distribution of the selected papers among the search engines





and one had 6 papers. Two researchers authored more primary studies namely Alexander Serebrenik (10), and Bodgan Vasilecu (7).

4 RESULTS

In this section, we present the results based on the seven perspectives

4.1 Representation of women in OSS projects

The primary studies identified women participation using a variety of methods, including mining software repositories and mailing lists and analyzing demographics from OSS surveys and mentorship programs. Table 3 summarizes the frequency reported by the primary studies.

Distribution of women in OSS found via mining software repositories. From a dataset of 23,493 GitHub projects, Vasilescu et al. [PS17] used the genderComputer tool [PS49] (with 93% of precision) to identify the gender, based on personal names, and, if available, countries, of 873,392 GitHub contributors. They found 91% men and 9% women. From a dataset of 8,338 GitHub projects, Prana et al. [PS16] found that the percentage of new GitHub accounts created by women has remained around 10% between 2014-2018. Bosu and Sultana [PS9] analyzed a dataset of 683,865 code review requests from 10 popular OSS projects. They found that women represent 6.70% (out of 4,543) of non-casual developers (those who submitted at least five code changes) and only 4.27% (out of 936) of core developers (those who are the top 10% developers in terms of the number of code commits in a project). Imtiaz et al. [PS3] used the same GitHub dataset and similar technique to infer gender and could identify 564,929 GitHub profiles into 529,253 men (93.7%) and 35,676 women (6.3%). From the 5,250 OpenStack contributors, Izquierdo et al. [PS12] inferred the gender and found that 10% are women. From a random sample of 300,000 GitHub users from a dataset with 16M users, Qiu et al. [PS46] identified 9.7% as women. Terrel et al. [PS4] analyzed a GitHub dataset with 4,037,953 profiles and identified the gender of 1,426,127 (35.3%) through their public Google+ profiles. From those profiles, the authors analyzed pull-request submission and acceptance by women and men and found that 8,216 of the pull-requests were submitted by women (5.2%) and 150,248 (94.8%) by men. Kofink [PS10] also analyzed a dataset of 1,811,631 pull-requests and found that 4.5% were submitted by women and 95.5% by men. Zacchiroli [PS44] also analyzed the authors of contributions. With 1.6 billion commits from the combined projects of GitHub, GitLab, and other development forges (using ²), corresponding to the development history of 120 million projects, the author found that contributions were authored by 33 million distinct people over 50 vears, and that in 2019 10% of all contributions to public code were authored by women.

Distribution of women in OSS found by mining mailing lists: Kuechler et al. [PS23] analyzed the participation in eleven mailing lists of six projects (Buildroot, Busybox, Jaws, Parrot, uClibc, and Yum), which totaled 3,310 subscriptions. Authors found low participation by women: 8.27% of all subscribers, 6.63% of those who posted one message, 2.5% of those who posted more than ten times, and 1.5% of code reporters. Vasilescu et al. [PS49] also used the mailing lists of two projects (Drupal and Wordpress) to explore women's representation and found that women authored 9.81% of the messages in Drupal and 7.81% in Wordpress. In contrast, both men and women engage in OSS projects for statistically similar lengths of time.

Distribution of women in OSS through surveys: Mani and Mukherjee [PS2] and Robles et al. [PS5] analyzed the same FOSS 2013 survey data [2]. This survey was answered by 2,183 OSS contributors, 226 of whom identified as women (10.35%). Lee and Carver [PS21] received 119 answers to their questionnaire where 10.92% of respondents identified as women, while Gerosa et al.'s [PS51] questionnaire received 224 answers with 7.6% who identified as women.

Distribution of women who participate in mentorship programs: By analyzing the gender of Google Summer of Code participants from 2016 to 2018, Canedo et al. [PS43] found that while there is a minor variation across the years, the volume of women stayed close to 11.98% of the total number of participants in the program.³

In summary, the primary studies reported women's participation ratios ranging between 4% to 14% (median 9.8%, as can be seen in Fig. 5a) across different measurements and OSS communities. When we analyze the distribution over time based on when the primary studies were published (Fig 5b), barring some fluctuation, women's participation ratio is more or less stable at around 10%. However, when taking a broader timeline view, Zacchiroli [PS44] through his analysis of public code contributions over the last 50 years found that women's contributions appear to be on the rise

²https://www.softwareheritage.org/

³The Google Summer of Code (GSoC) is a 3-month OSS engagement program that offers stipends and mentorship to students willing to contribute to OSS projects [75, 76, 84].

and are rising faster than those by male authors. This shows that while much still needs to be done, OSS projects are getting more gender diverse, albeit slowly.

Measure Women OSS contributors - survey (2013) [PS2, PS5] 10.4% Participation in Wordpress mailing lists (2014) [PS49] 7.8% Participation in Drupal mailing lists (2014) [PS49] 9.8% Authors of Pull-Requests (2015) [PS10] 4.5% GitHub users (2015) [PS17] 9.0% GSoC mentors 2016 [PS43] 7.8% GSoC students 2016 [PS43] 11.9% GSoC students 2016 [PS43] 11.9% GSoC students (2017) [PS43] 11.9% GSoC students (2017) [PS43] 13.4% GitHub committers (2018) [PS16] 10.0% OpenStack contributors (2018) [PS16] 10.0% GSoC students (2018) [PS43] 14.2% Core Developers (2019) [PS9] 4.3% Authors of Pull-Requests (2019) [PS3] 6.3% Non-Casual Coders (2019) [PS9] 6.7% GitHub users (2019) [PS46] 9.7% Authors of contributions to public code (2019) [PS44] 10.0% OSS contributors - survey (2019) [PS21] 10.9% OSS contributors - survey (2019) [PS21] 7.6%		
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	Authors of contributions to public code (2019) [PS44]	10.0%
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	OSS contributors - survey (2021) [PS51]	7.6%

Table 3. Frequency of women's participation in OSS as reported by primary studies (ordered by year)

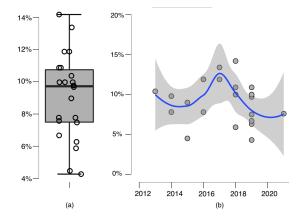


Fig. 5. The frequency of women's participation in OSS as reported by primary studies (a) per measurement and (b) per year. The values comprise percentages of women measured by different mechanisms.

Women represent about 9.8% of OSS contributors, considering different types of participation over the years.

	% Women
Mean	9.114
Median	9.750
Mode	10.000
Std. Deviation	2.654
Minimum	4.300
Maximum	14.200
25th percentile	7.525
50th percentile	9.750
75th percentile	10.775

Table 4. Descriptive statistics of women's participation reported by primary studies

4.2 Demographics of women contributors to OSS

To get a deeper understanding of the demographics of women who contribute to OSS projects, we analyzed available data reported in the primary studies along the following criteria: education level, time dedicated to contributions, diversification of projects, age range, family status, tenure, and geolocation (Fig 6).



Fig. 6. The characteristics of women who contribute to OSS projects

EDUCATION LEVEL. Based on Stack Overflow's 2018 developer survey that included 43,000+ OSS contributors, Wurzelova et al.'s [PS7] study reported that 82.8% of women who contribute to OSS are at least undergraduate students, against 76% of the overall rate of contributors [62]. Mani and Mukherjee [PS2] found a similar rate (81.4%) using data from the 2013 FLOSS Survey (226 women), while the corresponding figure for the whole dataset is 72%. All the 36 developers who identified as women on the survey from Canedo et al. [PS6] were at least undergraduate students. Manuscript submitted to ACM A substantial number of contributors from the three studies were post-graduates, who either achieved a Master's degree-11.6% [PS6], 27.6% [PS7]- or Ph.D.-4.2% [PS7], 10% [PS2], 22.9% [PS6].

VOLUNTEERING. Half of the 226 women (53.59%) who answered the 2013 FLOSS questionnaire devote less than five hours per week to OSS projects. Only 14.77% of the women who answered this questionnaire dedicate more than 40 hours per week [PS5], which can represent OSS as a full-time job. Although not mentioning the number of hours per week, according to the Powell et al.'s [PS28] results, 89% of women said they contribute to OSS both at home and at work, which includes bringing their work home and contributing to OSS during their leisure time.

DIVERSIFICATION OF PROJECTS. By mining data from software repositories, three studies [PS3, PS4, PS46] concluded that women concentrate their efforts on fewer projects than men. From a dataset of 152,534 pull-requests created by 20,926 women and 3,135,384 pull-requests created by 308,062 men, Imtiaz et al. [PS3] concluded that women's pull-requests are concentrated in fewer projects and fewer organizations than men's. Indeed, Qiu et al. [PS46] analyzed a balanced sample of the dataset, including 28,995 women and 29,096 men and also concluded that women tend to concentrate their contributions in fewer different projects than men. From a dataset of 1,426,127 users whose gender could be identified, Terrell et al. [PS4] analyzed the acceptance of submitted pull-requests and concluded that women contribute to fewer projects than men. From another perspective, Vasilescu et al. [PS1] ran a survey answered by 199 women and 611 men, in line with the previous studies, and concluded that women own fewer public repositories than men.

AGE. In different ways, four studies [PS1, PS5, PS6, PS8] show that most women who contribute to OSS are older than 20 and younger than 37 years old. According to the 226 women who answered the FLOSS 2013 questionnaire, the median age women join OSS is 26, the mean is 28, 1st Qu. is 22 and 3rd Qu. is 33, when many are already professionally active [PS5]. Having a similar result, the median age of the 199 women who answered the Vasilescu et al. [PS1]'s questionnaire was 29, the mean is 31, 1st Qu. is 24 and 3rd Qu. is 37. More than half (52%) of the 58 women who answered Singh's [PS8] questionnaire reported being 25-34 years old. Most of the 36 women who answered the Canedo et al.'s [PS6] questionnaire (80%) were younger than 35 years old.

FAMILY STATUS. Almost half of the 226 women who took part in the FLOSS 2013 survey are not married or do not live with their partners [PS2]. This rate was composed of 35% OSS single women, over 11% women not living with their partners, 3% living with their partners, 3% married, 0.1% separated from their partners [PS2] and 20% of those OSS women have children [PS2, PS5].

GEOLOCATION. The majority of women who participated in the primary studies were from Brazil (44% [PS1]), USA (37.1% [PS1]–40% [PS2]), and Germany (6% [PS2]–9% [PS16]–14.3% [PS1]). Considering the overall contributors from all genders, the USA is top ranked (25% [PS2]–32.6 [PS1]), followed by Germany (6.5% [PS1]–8% [PS2]). Brazil had only 2.7% of the overall contributors [PS1], but 44% of the overall women, showing that women stand out amongst contributors from this country.

TENURE. Most (77.2%) of the 199 women who answered Vasilescu et al.'s [PS1] questionnaire contribute to open source projects for fewer than five years. Authors found that women have on average six years of experience in IT/programming, a significantly lower tenure than men with nine years of experience;

The majority of women contribute to OSS projects for < 5 years, devote < 5 hours per week to OSS, are from multiple continents, are at least undergraduate students, with age ranging between 20-37 years, concentrate their work in a small number of repositories, projects, and organizations, and are mostly unmarried and with no children.

4.3 Types of contributions that women make in OSS projects

While the primary type of contribution in OSS projects is related to code development, the roles available in OSS projects go beyond the project-centric roles [85]. They include many people who work "behind the scenes" to drive and sustain the community [PS11]. We categorized the activities reported by primary studies according to a framework of OSS roles from a previous study [85] with two perspectives: coders or non-coders, and project-centric or community-centric (Fig.7). Afterward, we present details about women's contributions as coders and non-coders reported by primary studies.

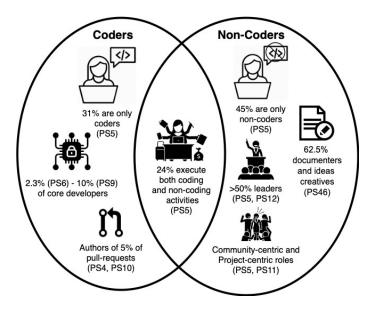


Fig. 7. Women make OSS contributions both as coders and as non-coders

4.3.1 Coders. Only 31% of the 226 women who answered the FLOSS survey [PS5] contribute to OSS projects are code developers, and 24% perform coding in parallel with other roles.

CORE DEVELOPERS. The classic hierarchical model of coders in OSS development communities is described as a core-periphery structure, with a small number of core developers and a large set of peripheral developers [60]. The core developers are code contributors involved with the OSS project for a relatively long time who make significant contributions to guide the project's development and evolution. Due to their relevant contributions and interactions, core developers often play leadership roles in OSS projects [94]. Related to these developers, Canedo et al. [PS6] found women as core developers in only 5.24% of the 711 GitHub analyzed projects. Of all the core developers, only 2.3% were women. From a dataset of 683,865 code review requests from ten popular OSS projects, Bosu and Sultana [PS9] found that women comprise a maximum of 10% of core developers among all ten projects. Following a classification of commit types from Hattori and Lanza [40], Canedo et al. [PS6] concluded that women who are core developers contribute more with corrective and reengineering commits than forward engineering and management commits. Moreover, when describing the commits, women present a more detailed message explaining their contribution changes than men. [PS15] evaluated the interactions in projects Angular.js, Moby, Rails, Tensorflow, Django, Elasticsearch and found that Manuscript submitted to ACM

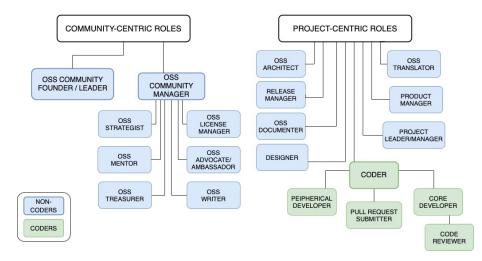


Fig. 8. Community-Centric and Project-Centric roles reported by primary studies as played by women who contribute to OSS. Roles can be played in parallel. Adapted from [85]

women who are core developers are more likely than men to interact with other contributors, evolve similarly to men within the project, and, though underrepresented, contribute to building sustainable social capital for OSS.

PREFERRED TECHNOLOGIES. From the 711 projects analyzed by Canedo et al. [PS6], women represented 8.8% of the core developers in projects that are based on *Scala* programming language, 8.7% when is *CSS*, 6.3% when in TypeScript, 5.6% when is Swift, only 1% when the project is based on PHP and Shell programming languages. Still, from the same data, even projects written in TypeScript (10.93%) have at least one woman as a core developer, and 2.17% of projects using PHP have at least one woman as a core developer. Considering the data from the six projects analyzed by El Asri and Kerzazi [PS15] (Angular.js, Moby, Rails, Tensorflow, Django, Elasticsearch), women represented at least 4.8% of core developers for the projects based on Python, at least 4.5% for C++, and at least 4.2% for Java. From the 158,464 of pull-requests for which Terrell et al. [PS4] could identify gender, women had a greater rate of accepted pull-requests in Ruby, Python, and C++. We present the percentages of women as developers for each programming language as reported in the primary studies in Fig 9.

CODE REVIEWERS. Peer code review is a practice in software engineering. A code developer submits the code produced to another person (peer) to evaluate and find possible errors before merging the code to the project codebase [3]. According to the GitHub dataset of six projects evaluated by Paul et al. [PS13], women are more likely to write reviews expressing sentiments in the text to another woman than to a man during code reviews. Huang et al. [PS14] used medical imaging and eye-tracking to evaluate the visual and cognitive processes and patterns of neural activation followed by reviewers while performing code reviews. Authors found that women spent significantly more time analyzing pull-request messages and author pictures (regardless of their identity) than the code itself when performing code reviews.

4.3.2 Non-Coders. Almost half (45%) of the 226 women who answered the FLOSS 2013 survey take part in non-coding activities, and 24% perform code-related activities in parallel with other roles [PS5].

OSS COMMUNITY MANAGER. After analyzing the career pathways followed by 17 contributors, Trinkenreich et al. [PS11] presented a set of community-centric roles, including community founders and managers, strategists, mentors, Manuscript submitted to ACM

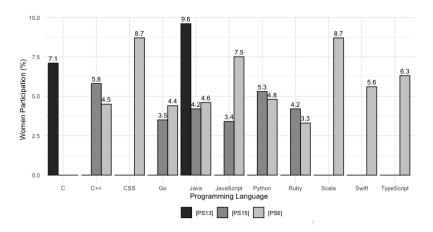


Fig. 9. Women's participation as core Developers in OSS per programming language

writers, license managers, treasures, and advocates. The contributors who play these roles are usually "hidden figures," who are not visible when analyzing the data from projects' repositories or coding platform websites. 11 (out of the 12) women interviewed in this study play community-centric roles.

PROJECT LEADER/MANAGER. More than half (51.49%) of the 226 women who answered the FLOSS 2013 survey participate in community leader, coordinator, or administrator roles, while only 5% of those women coordinate more than three projects [PS5]. Women in OpenStack who play leadership roles represent 7% of the project committee members, 8% of the project team leaders, 9% of the project board directors, 7% of the technical committee, 8% of the working group leaders, and 23% of project ambassadors [PS12].

Women are more present in community-centric roles; 45% of them make non-code contributions. However, they often play both coding and non-coding activities in parallel. Only 5% of projects have at least one woman as a core developer. When reviewing code, women also read pull-request messages and analyze the author's pictures.

4.4 Rate of acceptance of women's contributions in OSS projects

For code contributions, we used the merge rate of pull-requests as a measurement of women's contributions' acceptance. Kofink [PS10] analyzed 1,811,631 pull-requests from 1,049,345 different users and found that women's pull-requests account for only 4.5% of the total. Terrell et al. [PS4] presented a similar rate: women submitted 5% of the pull-requests (from 158,464 in which authors could identify gender) and tend to have their pull-requests accepted at a slightly higher rate (78.7%) than men (74.6%), regardless of experience level. Authors found that, while less experienced developers making their initial pull requests do get rejected more often, women generally still maintain a higher rate of acceptance throughout. Even submitting fewer pull-requests, according to Kofink [PS10], women have 64.2% of merge acceptance rate, nearly equivalent to men's (63.9%), and continue to have high acceptance rates as they gain experience. According to Huang et al. [PS14], humans (non-bots) are 4.7% more likely to accept pull-requests submitted by women than men. On the other hand, Terrell et al. [PS4] found that women have a 12% lower pull-request acceptance rate when they explicitly identify themselves as women, comparable to 3.8% for men who disclosure their gender. Even in a population of core developers, one-third of the 36 women who answered Canedo et al.'s [PS6] survey reported they Manuscript submitted to ACM

believe that reviewers had not accepted at least one of their contributions due to gender bias. Moreover, 11.4% women often recognize gender bias while someone assesses their contributions.

Women author less than 5% of pull-requests. However, they have similar or even higher rates of merge acceptance than men. On the other hand, women frequently report biases and they have lower acceptance rates of their pull-requests when they explicitly identify themselves as women.

4.5 The motivations that drive women to participate in OSS projects

We consolidated the studies reporting women's motivation to participate in OSS projects, aggregating the results according to Von Krogh et al. 's categories [90]. Von Krogh et al. [90] surveyed the literature and identified ten categories of motivation, grouped as intrinsic, internalized-extrinsic, and extrinsic. Intrinsic motivation (Enjoyment and Fun, Kinship, Ideology, and Altruism) moves a person to act for the fun or challenge entailed rather than in response to external pressures or rewards [72]. In contrast, extrinsic motivations (Career and Pay) are based on outside incentives when people change their actions due to an external intervention [31]. Contributors can also internalize extrinsic motivators (Learning, Own-Use, Reciprocity, and Reputation) as self-regulating behavior, rather than as external impositions [21, 68]. We summarize our findings organized in these higher level categories in Table 5 and Figure 10.

Categories [90]		Women's motivations to participate on OSS
	Enjoyment and Fun	Contribute when "find it exciting" [PS18], have fun and feel stimulated by
		writing programs[PS51].
	Kinship	Work on a project with friends [PS16] and participate in new forms of cooper-
Intrinsic		ation [PS5][PS51]
mumsic	Ideology	Believe that source code should be open and want to limit the power of propri-
		etary software companies [PS5] [PS51]
	Altruism	Share knowledge [PS5][PS51], improve other developers' code [PS5], help
		people and practice philanthropy [PS19]
	Career	Improve career [PS51] and have more job opportunities [PS5].
Extrinsic	Pay	Being paid to contribute or selling products and services related to OSS
		[PS16][PS51].
	Learning	Learn, develop and improve skills [PS5][PS51]
Internalized Extrinsic	Own-Use	Employment needs to use [PS50] [PS51]
	Reciprocity	Feel personal obligation because they use OSS [PS51]
	Reputation	Want to enhance my reputation [PS51]

Among all 10 categories, the literature showed that women see ENJOYMENT AND FUN, RECIPROCITY, KINSHIP, and PAY a little differently from the motivation literature [34, 38, 44, 50, PS51] —which is based on surveys answered predominantly by men—reports. ENJOYMENT AND FUN has been consistently reported as a top driver to contribute to OSS in motivation surveys [34, 38, 44, 50, PS51]. However, according to the stratified analysis on Gerosa et al.'s [PS51] study, no women reported this motivation to join (and one–6%–stayed because of this), while 7% of the men joined motivated by fun and 20% continued because of it.

The opposite trend is observed for RECIPROCITY, KINSHIP, and PAY. RECIPROCITY appeared as one of the top motivators for women in Gerosa et al.'s [PS51] work, who reported that 39% of the women reported this as motivation to continue Manuscript submitted to ACM

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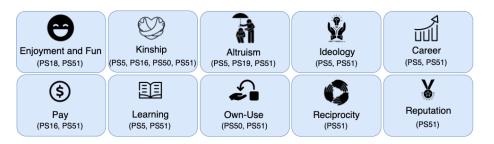


Fig. 10. Women's motivations to contribute to OSS. Based on [90]

(versus 15% of the men). In general surveys [50, PS51], reciprocity is not among the top motivators. Regarding KINSHIP, while 39% of the 226 women who answered the FLOSS survey joined because of this motivation, 31% continued because of it [PS5]. Most (64%) of the 22 women who answered Prana et al.'s survey [PS16] select a project in which friends and colleagues also participate. As part of kinship, peer parity also plays a role in women's motivation [PS50]. David and Shapiro [PS50] found that social connections with other developers influence women's choices. However, no women from Gerosa et al.'s [PS51] study joined OSS because of kinship. Kinship is not top ranked in general surveys [34, 38, 50], but this trend has been changing with the rise of social coding platforms [PS51]. Regarding PAY, Prana et al. [PS16] indicated that payment is a greater incentive for women than men (64% vs. 35%). This was echoed by women interviewees from Balali et al. [PS18]. However, the difference was not noticed in Gerosa et al.'s [PS51] work, in which men and women equally reported money as a reason to continue contributing (14% and 11%, respectively).

For other motivations, we found that women follow a similar trend as reported in the general literature. LEARNING, for example, has been frequently reported as a key motivation to contribute to OSS [34, 38, 44, 50] and most (68%) of the 226 women who took part in the FLOSS 2013 survey joined for LEARNING and 65% continue because of it [PS5]. The same happens for ALTRUISM. It is a common OSS motivator in OSS [34, PS51] and it is relevant for women as well—37% of the women who took the FLOSS 2013 survey reported that they joined to share knowledge [PS5] and 22% from another work continued because of it [PS51].

Similar rates were also found for CAREER, OWN-USE, and REPUTATION. Regarding CAREER, only 4% of the 226 women who took the FLOSS 2013 survey and none who took Gerosa et al.'s [PS51] survey reported joining to improve their careers. Similar rates were found for men (5% and 8%, respectively). For OWN-USE, David and Shapiro [PS50] found that women are motivated by their employment-related needs and one third (6 out of 18) of the women from Gerosa et al.'s [PS51] reported this motivation to join OSS. This is in line with previous research that shows that women are motivated to use technology for what it enables them to accomplish [10]. REPUTATION was not a top motivation for contributors from all genders in the early 2000s [34, 50] and is still not. Only 4% of the men from from Gerosa et al.'s [PS51] joined because of reputation, while no women reported it.

Finally, an interesting case was IDEOLOGY, which was top-ranked in general surveys about motivation to join OSS [34, 38, 44, 50] from the 2000s. Ideology is usually captured by motivations as "software should be free for all," "free to modify and redistribute," or "OSS should replace proprietary software." [90]. In the recent survey by Gerosa et al. [PS51], this motivation has dropped some and was mentioned as a reason to join by only 11% of the women and 11% of the men. When considering only women, we can see that there was also a drop compared to the FLOSS survey, in which ideology was mentioned by 28% of the women [PS5].

Reciprocity, Kinship and Pay are motivations specially relevant for women. On the other hand, enjoyment and fun motivate men more than women. Altruism, learning, and own-use motivate both men and women, career and reputation are low-ranked for both genders, and ideology was relevant in the past but lost importance for both genders over the years.

4.6 The challenges faced by women when contributing to OSS projects

Women mainly face social challenges when contributing to OSS [PS21], which can also influence their decision to leave an OSS project [PS13]. In Powell et al.'s [PS28] survey, 37 women answered; 50% of them indicated they had witnessed gender-based discrimination within the OSS community either online, in meetings, or in class, and 50% said they had experienced harassment online or offline. Gender-related incidents can be so severe that they motivate women to leave an OSS project [PS1]. Indeed, in another survey [PS21] women reported that they drop out when the OSS project does not care about diversity. Leaving an OSS project is a decision that impacts more women than men—according to Qiu et al. [PS46], and women are more likely to disengage from GitHub by 27%. Understanding the reasons behind the decisions to step out of a project can help create strategies to increase retention in OSS. Kuechler et al. [PS23] suggest that women drop out because the OSS project is not aligned to their motivations or due to the unappealing and hostile social dynamics in projects. We summarize the challenges, which were all social, in Table 6 and Fig. 11 and mark with an asterisk (*) the ones reported as a challenge that ultimately can cause women to leave OSS. Next, we present and explain each of them.

Challenge	Description	
Lack of Peer Parity	Women feel alienated [PS28], frustrated [PS1], invisible [PS24] and less comfortable without	
	other women around [PS18], specially in medium-size projects where all contributors [PS27].	
Non-Inclusive	The expletives often used in the mailing lists [PS13], documentation [PS18] and code re-	
Communication	views [PS27] are insulting to women and can cause them to leave an OSS project [PS13].	
Toxic Culture	Incidents of symbolic violence, harassment [PS24] and sexism against women [PS22] bring	
	hostility [PS25] and can hinder their access to the community [PS21], as they may already be	
	hesitant about how they will be received [PS23].	
Impostor Syndrome	Even being competent [PS32] and knowing the importance of confidence [PS28], women face	
	a lack of self-efficacy [PS18] [PS21, PS29, PS30, PS31], are more restrained [PS3] and reluctant	
	to publicly display their work [PS1] than men in general	
Community	Finding a mentor is a hard task [PS21], as men consider as a dating opportunity [PS22], which	
Reception Issues	leads many women to hide their gender [PS1] and feel restrained when being repealed by	
	communities for not being ready to provide contributions soon [PS20].	
Stereotyping	Women are being boxed into specific roles [PS24] [PS26], sometimes treated by men as if they	
	were their mother for who they ask how to dress and behave [PS22]	
Work-Life	Lack of time due to family responsibilities [PS21]	
Balance Issues	Lack of this due to failing responsibilities [F321]	

Table 6. Challenges faced by women when contributing to OSS projects

LACK OF PEER PARITY. Most women (72%) feel outnumbered and 24% feel alienated [PS28]. Women reported to feel more comfortable and accepted by their same gender counterparts [PS18] and feel frustrated when there is no peer parity [PS1]. This problem worsens in medium-size projects in which all contributors are men, as they may form a Manuscript submitted to ACM



Fig. 11. Challenges faced by women when contributing to OSS

clique that a woman contributor could have difficultly breaking into [PS27]. *"It is not so common to find many girls in technical teams"* [PS6], and in the face of this lack of parity women reported to feel invisible in larger majority-men groups [PS24].

NON-INCLUSIVE COMMUNICATION. Expletives often used in the mailing lists are insulting to women. The negative workplace experience of encountering words that are demeaning to them in the mailing lists can cause women to leave OSS projects [PS13]. Awkward communication styles [PS18] on acrimonious talk about which code piece should be incorporated [PS22], and terms usually associated with men (e.g., "guys") can demotivate women [PS27].

TOXIC CULTURE. Incidents of symbolic violence and harassment against women can hinder their access to the community, as when men decide to 'Hire that one because she is hot' [PS24]. Geek-saturated communities like Slashdot are often unwelcoming and hostile environments [PS25]. Additionally, women are sexualized in OSS [PS8], facing judgment, abuse, hostility, and discrimination [PS42]. While hurtful and offensive talk is openly addressed to them, women are obliged to remind men not to "stare and point" at them [PS22]. From the 13 women who answered a questionnaire sent to 15 OSS projects, 38% had suffered some incidents of sexism, including sexist statements or assumptions, being ignored, insinuations that they had it easy because they were women, and being simultaneously held to higher standards than men and underestimated [PS21]. Moreover, the authors found that women had trouble being taken seriously and needed to prove themselves (prove-it-again [PS3]). According to to [PS23], public flaming and aggression can be enough to distort women's participation, as they may already be hesitant about how they will be received.

IMPOSTOR SYNDROME. Women tend to be risk-averse [23] and have low computer self-efficacy [10, 12, 16, 39, 45, 77], which can affect their behavior with technology, causing women to be less confident in their ability to complete tasks and blame themselves if there is a problem [PS29, PS30, PS31]. Women find it challenging to directly translate competence to confidence without social attraction (being liked by the other community members in terms of having a rapid increase of followers). Consequently, initiating a pull-request to a new repository can be problematic due to women's competence-confidence gap [PS32]. Even understanding that confidence is an essential factor when entering OSS [PS28], women face a lack of self-efficacy [PS21, PS18]. "Despite having proved [their] competency in certain areas of the code/project, [their] opinion is rarely or never asked for" (quotation from Vasilescu et al. [PS1]). Still, Imtiaz et al. [PS3] found that women tend to be more restrained than men in general. Despite being knowledgeable and professionally well-settled, women may be more reluctant to publicly display their work [PS1].

COMMUNITY RECEPTION ISSUES. Women reported to feel restrained when communities nullify them when they do not have enough skills to provide contributions since the first day [PS20]. When trying to find a mentor, upon discovering their mentee's gender, men mentors can treat the relationship as a dating opportunity [PS22]. This makes finding a mentor an arduous task, which includes attracting attention and breaking into a close-knit OSS community [PS21]. Many women use a fake GitHub and hide their gender, *"so that people would assume [they] were male"* [PS1].

STEREOTYPING. Pre-existing stereotypes [PS8, PS28], gender roles, and "macho" attitudes can cause gender inequalities in OSS communities [PS24]. Women are boxed into specializations despite their manifest protest against it, as the legal case against the front-end/back-end distinction has shown [PS26]. Additionally, men often treat women as if they were their mother, asking for advice about how to dress and behave and then refusing to enter into a technical dialogue thereafter [PS22].

WORK-LIFE BALANCE ISSUES. Women that participated in Lee and Carver's [PS21] study reported a lack of time and family responsibilities. Only women from this study reported family responsibilities as a challenge.

Women face social challenges that include: missing having other women around (lack of peer parity), insulting expletives in mailing lists (non-inclusive communication), suffering symbolic violence and harassment (toxic culture), avoiding initiating a pull-request due to lack of confidence (impostor syndrome), facing challenges asking men to serve as their mentor (community reception issues), being boxed into specific roles (stereotyping), and sharing time between work and family (work-life balance issues).

4.7 The strategies been proposed for OSS communities to increase women's participation in OSS projects

Strategies include actionable mechanisms that OSS communities can take and combine to create a more inclusive environment for women in OSS. We summarize the propose strategies in Fig. 12 and Table 7. Next, we present and explain each of them. All strategies had been mentioned as a way to mitigate at least one challenge presented in Sect. 4.6. However, there was no strategy reported to mitigate the challenge WORK-LIFE BALANCE ISSUES.

PROMOTE AWARENESS OF THE PRESENCE OF PEERS. Half (54%) of the women respondents of Powell et al.'s [PS28] study said they would be more inclined to participate in OSS if there were more women involved. Promoting awareness about the rate of women can help to attract more women, minimizing the feeling of alienation [PS28]. The awareness should include a measurement of women's participation and the type of contributions [PS12, PS39]. According to participants of Calvo's [PS24] study, the communities can generate parallel spaces in which the proportion of women is above 50% so as to create more diverse environments under the values of mediation and care.

PROMOTE WOMEN-SPECIFIC GROUPS AND EVENTS. The community managers interviewed by Calvo [PS24] mentioned that they promote schoolgirls' events to inspire vocations and empower girls who may opt for an OSS career. This strategy should promote activities exclusively for women in those spaces, highlighting their presence, as women tend to be invisible in larger groups in which men are the majority [PS24]. For those women already interested in OSS, promoting women-only groups, spaces, and events [PS6, PS8, PS24, PS42, PS28, PS47] fosters discussions, support networking, and empowerment [PS42]. Moreover, it provides a safe space for expressing feelings and opinions [PS24] and revealing their identities [PS47]. Although effective, Singh and Brandon [PS47] found that only 3% of the 350 projects they analyzed have women-specific spaces—including websites, IRC Channels, dedicated blogs, collection/list of resources, dedicated Facebook pages, and local meet-ups.

Table 7. Strategies to increase women's	participation in OSS projects
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Strategy	Description
Promote awareness of the presence of peers	Reduce the lack of peer parity by having more women involved [PS24] [PS28] and propagating their participation [PS12] [PS39].
Promote women-specific groups and events	Awake technological vocations with schoolgirls' OSS events [PS24] and code development training [PS35], create forums and women-only spaces [PS6] [PS8] [PS24] [PS42] [PS28], and facilitate women's registrations and participation in events [PS47].
Promote inclusive language	Avoid gender pronouns [PS6] that assume that people are [all] the same gender [PS27].
De-stereotype the OSS contributor	Fix and do not stereotype activities on gender [PS8] [PS28], as code development for men [PS6] [PS26] and community management for women [PS24].
Encourage and be welcoming to women	Have women encouraging other women [PS16] [PS25] to make code [PS28] and also non-code contributions [PS32], increasing their confidence [PS6], while making the community friendly and supportive [PS8] [PS39] [PS41].
Promote women to leadership roles (empowerment)	Train women in leadership skills [PS9] [PS38], promote them to senior, decision- making positions, [PS6] [PS8] [PS16] [PS24] and mediating [PS36] roles.
De-bias tools	Use the Gendermag technique to find bias in tools, and use recommendations to adjust the software, making it more inclusive to the women's cognitive style [PS29] [PS30] [PS31].
Recognize women's achievement (visibility)	Showcase the success of women [PS16] [PS42], celebrate their achievements [PS3], recognize their efforts [PS32] and give credits when they deserve it [PS8], using either the communication channels [PS6] and events in which they can be speakers [PS24].
Prepare Mentors to Guide Women	Train mentors to guide women [PS8] [PS39] [PS40] [PS42], bring cultural prox- imity between mentors and mentees [PS16], making sure novices find the help and support they need [PS23] [PS24].
Create and enforce a Code of Conduct	Develop a code of conduct [PS3] [PS16] [PS27] [PS47] as the collective norms on (un)acceptable behavior at all interactions, explicit the prohibition of harassment [PS21] [PS24] [PS37], and that violations have consequences [PS8] [PS33], while having mechanisms to invigilate the use and to apply the punishments accordingly if necessary.

PROMOTE INCLUSIVE LANGUAGE. Avoid gender pronouns that assume that people are [all] one gender or one demographic [PS27]. For example, using 'guys' is very common, and it gives an idea that contributors are men [PS6].

DE-STEREOTYPE THE OSS CONTRIBUTOR. The women interviewed in Singh's [PS8] study recommended to "leave the stereotypes out the door." The frustration caused by stereotypes was expressed by one of the women surveyed by Canedo et al. [PS6]: "Stop treating women developers as 'women developers' and start treating them as developers." Powell et al. [PS28] suggests showing less discrimination and more inclusion to tone down the male-dominated atmosphere and promote participation. Calvo [PS24] and Vedres and Vasarhelyi [PS26] suggest avoiding the *feminization* of specific assignments, like those relating to community building tasks; OSS communities should re-classify types of work that used to be packaged in masculine-feminine stereotyped specialties.

ENCOURAGE AND WELCOME WOMEN. Singh's [PS8] findings show that being less judgmental and appreciating diverse teams is essential to supporting and encouraging women. Indeed, as Beach [PS41] discusses, people need to feel supported, accepted, and encouraged. This encouragement may even come from other women [PS16]. Powell et al. [PS28] suggested starting by encouraging small steps as an incentive to women to submit bug reports and share their input, which was echoed by two participants of Canedo et al.'s [PS6] study, "the solution is to build confidence" and "not to fear when contributing." This would increase their self-confidence [PS25].Encouragement is also the goal of some initiatives presented by Parker's [PS25] FLOSSpols⁴, which offers recommendations on how to solve the gender gap; these initiatives include WOWEM, a gender equity and OSS research and education project; and LinuxChix, a community for supporting women in Linux. There is no value in encouraging women to be there if the environment is hostile. To welcome women, one of the community managers who participated in Barcomb et al.'s [PS39] study recommends making the community friendlier in general.

PROMOTE WOMEN TO LEADERSHIP ROLES (EMPOWERMENT). A way to empower women is to have them in senior roles [PS6], in project governance [PS38], and where appropriate [PS8], as mentioned by one woman participant of Prana et al.'s [PS16] study: "More women reviewers. More women are acting directly on the governance of large OSS projects". Some community managers indicated their communities created decision-making positions and ensured that women led public activities [PS24]. Catolino et al. [PS36] suggested that a way to avoid the proliferation of community smells is to involve women in positions where they can mediate discussions and improve the communication of sub-communities. According to Singh [PS8], promoting women to positions of authority shows the project respects their contributions.

DE-BIAS TOOLS. Most (73%) of the barriers that affect software professionals have some form of gender bias [PS29]. Indeed, bias in tools and infrastructure can hinder women newcomers from joining OSS [PS29]. One way to de-bias infrastructure and tools is by applying the GenderMag technique. GenderMag uses personas and a specialized Cognitive Walkthrough (CW) to systematically evaluate software and make them more inclusive of the women's cognitive style [PS29, PS30, PS31]. This technique's precision was proved by a lab study that showed that the GenderMag technique helped to identify 81% of the issues [11].

RECOGNIZE WOMEN'S ACHIEVEMENT (VISIBILITY). When recognizing women's achievements, the community provides the social attraction that women seek to overcome their competence-confidence gap [PS32]. Communities can show recognition by increasing the visibility of women [PS16], listing them as great contributors whenever they deserve it [PS42], and *publicly* celebrating their achievements in blogs, project homepages, and social media [PS3, PS16]. Another way to increase visibility is to organize events where speakers are women [PS24, PS47]. These simple actions inspire more women to participate [PS16, PS24].

PREPARE MENTORS TO GUIDE WOMEN. As mentioned before, OSS projects are usually men-dominated environments, which may scare women away [86, PS22]. Mentorship can help women newcomers find the assistance and support they need [PS23, PS24, PS39]. One way to do so is to have women mentor other women [PS8, PS42]. Singh [PS8] highlights that when mentoring women it is necessary to guide them on different aspects. While men need to change their behavior and projects need to implement systemic changes, Singh [PS8] posits that women also need to be trained to ignore disruptions and not be easily bothered by criticism or insults; the mentor needs to be extra supportive, friendly, respectful, and encouraging [PS8].

⁴www.flosspols.org

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CREATE AND ENFORCE A CODE OF CONDUCT. Developing a code of conduct for the community [PS3, PS8, PS16, PS24, PS27, PS33, PS37, PS47] helps to mitigate Tightrope effects⁵ by assisting communities in articulating acceptable behaviors for all members [PS8]. The code of conduct comprises the collective norms of a community, as mantras to shape the culture of collaboration [PS37], the community's expectations and values to create a friendly and inclusive community [PS8, PS33]. While having a code of conduct will not prevent sexism, it indicates to any men who have firmly held anti-female behaviors that such actions will not be tolerated in the project [PS21]. However, according to Robson's study [PS34], just creating a code of conduct will not increase women's participation. The author showed that projects that introduced a code of conduct. Projects increased from 2.37% to 3.81% after a code's introduction. Projects without codes of conduct, comparing gender diversity within similar periods yields, had an increase from 4.10% to 5.53%. The average increases were 1.44%, and 1.43%, respectively, which means creating the code of conduct did not help increase women's participation. Robson [PS34] posits that the code of conduct needs to be enforced among the project members. Indeed, it is necessary to have mechanisms in place to implement the code and show that violations have consequences [PS8, PS33].



Fig. 12. Strategies employed by OSS communities and projects to increase women's participation in OSS

The strategies that OSS communities can employ to increase women's participation include providing awareness and numbers about women contributors, inclusive language, women-specific groups and events, de-stereotyping the OSS contributor, encouraging and welcoming women, having women in leadership, de-biasing tools, recognizing women's achievement, preparing mentors to guide women, and creating and enforcing a code of conduct.

5 DISCUSSION

In this section, we discuss our results.

Spread the word and recognize women's success. Impostor syndrome is a psychological concept about a pattern of behavior wherein people (even those with adequate external evidence of success) doubt their abilities and experience a persistent fear of being exposed as a fraud [57]. As we presented in Section 4.3, the literature shows that when women join OSS, the rate of acceptance of their contributions is similar to (if not higher than) men's. The IMPOSTOR SYNDROME

⁵The term Tightrope is usually associated with the circus, where a performer walks on a stretched rope. Following an analogy, the term can refer to the narrow band of socially acceptable behavior for someone, in our case, women [PS3].

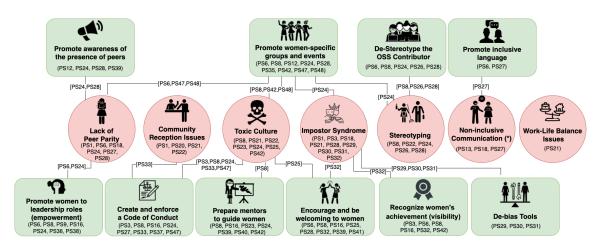


Fig. 13. The strategies that were mentioned by primary studies to mitigate challenges faced by women in OSS (circles represent challenges and rectangles represent strategies)

in OSS can arouse from the hostile and TOXIC CULTURE that pervades communities, which are two of the challenges we found in the literature and were presented in Section 4.6. The impostor syndrome disproportionately affects women and other minority groups, who often lack sufficient role models of success [57]. In that sense, the strategies of PROMOTING AWARENESS ABOUT HAVING OTHER WOMEN and RECOGNIZING WOMEN'S ACHIEVEMENT (VISIBILITY) that we presented in Section 4.7 can help to reduce the impostor syndrome that women reported to feel. The benefits of combining these two strategies are two-fold. While recognition support the retention of existent women, it also attracts new women who can see they can have similar success achieved by their peers. Those strategies have been applied in STEM and other domains. Publicizing success stories of women in STEM was a strategy used to attract more women in Latin America in STEM higher education programs [33]. Establishing prizes and awards is a strategy that approximately 82% of U.K. research institutions have applied to stimulate and attract more women in STEM [26]. In automotive industries, specific groups publish articles about women and recognize leading women personalities through e-news [81]. As in other domains, OSS projects should implement different mechanisms to reward and promote awareness of women, motivating them to stick around.

Believe in OSS as a career. As we could find in Section 4.4, only 4.07% of the 226 surveyed women from the FLOSS 2013 study joined to increase their job opportunities. After becoming contributors, this motivation increased almost six times (going to 25.79%) [PS5]. We argue that this represents the "shifting belief" that women have in OSS toward building a career, which increases only after overcoming the barriers to join and become contributors. The multiple roles presented in Section 4.3 are both related to the technical (project-centric) and non-technical (community-centric) side of the projects. Awareness of the different roles and career pathways that exist in OSS can attract women with diverse backgrounds and expertise to OSS by showing them the multitude of trajectories to success [PS11].

The misalignment between women's motivations and challenges. If women have social motivations (e.g. KINSHIP) as we presented in Section 4.5, and the reported challenges are also social, as we presented in Section 4.6, there is a conflict between expectations and reality, which can explain why women are not joining or staying in OSS projects. When women join an OSS project expecting to find other women [PS50] and friendly colleagues [PS16], but instead find LACK OF PEER PARITY and face a TOXIC CULTURE, this directly conflicts with their motivations. Manuscript submitted to ACM

Women-specific spaces. When offering women-only spaces, OSS communities show they are welcoming women [PS6]. According to one interviewee from Calvo's [PS24] study, "when you send things directly to women, they become a lot more involved". Women tend to hide their identities and gender to avoid bias and protect themselves [PS1], but not in women-specific spaces, demonstrating they felt safe and comfortable in those spaces [PS48]. Participants from Canedo et al.'s [PS6] study mentioned some specific initiatives (e.g., Outreachy⁶ and local meetups) that might help to attract more women. Summer of Code events offer a diverse set of motivations and enhance the participants' sense of competence, autonomy, and relatedness, increasing the chances of future contributions as they internalize OSS projects' culture and values [74]. Although it is pretty clear that women-specific spaces and events are essential to create safe spaces and make women comfortable, these spaces are still not commonplace—found in only 3% of the 350 projects analyzed by Singh and Brandon [PS47]. Therefore, community building teams and maintainers must foster these kinds of efforts to make women start reporting to feel welcome and supported.

Codes of conduct: reward who follows, punish who violates. Robson [PS34] concluded that it would make litter difference to have a code of conduct unless it is enforced among the project members. The authors showed no significant difference in the proportion of women contributing to projects with or without a code of conduct. Enforcing compliance with codes of conduct can be supported by tools like bots [91, PS8]. Even though highly suggested by the literature as a strategy to increase inclusion, Singh and Brandon [PS47] found that only 8% of the 355 sites of OSS projects that authors investigated have a code of conduct. To promote OSS projects to adopt a code of conduct, Prana et al. [PS16] suggested creating a reward program to recognize the projects that have one (e.g., GitHub could offer donation through sponsors, badges, etc.).

No stereotypes, please! According to a survey of 5,500 GitHub users [95], women more often than men encounter language or content that makes them feel stereotyped. Stereotypes manifest the common expectations about members of certain social groups. Both descriptive (how women are) and prescriptive (how women should be) gender stereotypes and the expectations they produce can compromise a woman's career progress [41, 42]. Even before starting a career, stereotype threats represent one of the significant barriers to underrepresented groups engaging in Computer Science education. Implicit stereotypes about gender and STEM have profound effects on girls' and women's interest, confidence, and persistence in STEM education and careers [19, 20]. Being afraid of stereotypes can motivate women to hide their gender [PS1] and create pseudonyms to avoid judgment [PS21]. This behavior was also observed by Ford et al. [28] in online communities, where participants use a "gender neutral alias for websites like technical communities, because [they] get better help when asking questions or answering them." One of the strategies presented in Section 4.7 is DE-STEREOTYPING THE OSS CONTRIBUTOR, which differs from using a neutral username to hide gender. In fact, Canedo et al.'s [PS6] study showed that users who do not reveal their gender suffer an even more severe disadvantage in survival probability. Although it prevents discrimination by categorical gender, avoiding gender identity can also lead to a lack of trust and exclusion from projects and ultimately cause a higher exit rate of such users. Stereotypes can be minimal but still makes a difference. People's attitudes, beliefs, and behavior are often shaped by factors that lie outside their awareness [5, 36]. Considering that even minimal social cues may activate negative stereotypes early in informational processing [92], DE-STEREOTYPING THE OSS CONTRIBUTOR is crucial for women to start seeing themselves playing the role of developer and not just men. This strategy is aligned to the suggestion of women interviewed in the Blincoe

⁶ Outreachy (https://www.outreachy.org/) is a paid, remote internship program that aims to support people from groups underrepresented in technology, such as women, helping newcomers to OSS to make their first contributions. Interns work with experienced mentors from OSS communities in a diverse set of activities, including code development, user experience, documentation, illustration, graphical design, or data science. More than 90% of past interns are women.

et al.'s study [8], who considered that changing the typical image of software engineers as men IT geeks is a way to reduce the gender gap.

Women are as efficient as men... maybe even more. Based on the two code contribution metrics (i.e., code churn per month and code changes per month), Bosu and Sultana's [PS9] evidenced the absence of significant differences when comparing men and women developers in terms of productivity. Moreover, the authors suggest that women are as productive as their male colleagues in an inclusive OSS project, with some women developers demonstrating more productivity than the average men developers. Even not supporting any inferences about whether men or women are more accurate at code review, results from Huang et al. [PS14]'s study indicates women present more reliable activity patterns.

Free two birds with one key. OSS communities can implement single but structured actions combining ideas from more than one strategy to increase women's participation. By publishing success stories of women on media, OSS communities can promote AWARENESS OF PRESENCE OF PEERS to attract more women and also RECOGNIZE WOMEN'S ACHIEVEMENT (VISIBILITY) to retain women who are already contributors. Considering that this media exposure can include women's posts and pictures, the action also attends the strategy of DE-STEREOTYPE THE OSS CONTRIBUTOR, which is usually associated with the image of men. Another action that can attend more than one strategy is to create a women-only forum, which is part of the strategy to promote WOMEN-SPECIFIC GROUPS AND EVENTS. When moderating and analyzing the messages to implement feasible changes to problems that are being actively discussed, this action also acts to ENCOURAGE AND BE WELCOMING TO WOMEN, offering mentorship or inviting women to contribute to specific activities directly. One more action that can be be adopted in multiple strategies is to CREATE AND ENFORCE A CODE OF CONDUCT and associated online training, being transparent about the punishments for those who act against it. There can be one training for contributors in general and another one for mentors to (PREPARE MENTORS TO GUIDE WOMEN), showing practical examples of acceptable and non-acceptable behaviors. Communities can use mining tools to identifying gender pronouns in messages of mailing lists, pull-requests, and code reviews and help to PROMOTE INCLUSIVE LANGUAGE. The authors of those messages can be individually contacted and even receive the non-compliance punishment.

5.1 Gaps in the literature and open opportunities.

This subsection builds upon the discussion and summarizes the gaps in the literature that may be explored by researchers, in addition to the opportunities for women, practice, and education.

Researchers: Although several strategies to increase women's participation have been proposed in the literature [PS6, PS8, PS16, PS24, PS27], most papers do not present scientific evidence about the effectiveness of these strategies. For instance, Tourani et al. [PS33], Imtiaz et al. [PS3], and Vandana and Brandon [PS47] called for further research to evaluate the effectiveness and best practices related to code of conduct, despite being one of the most cited strategy to promote women participation. Izquierdo et al. [PS12] discuss the difficulty of evaluating the effectiveness of strategies, as communities need to have consistent measurements before (baseline), during, and after their implementation. The authors reported that, although OpenStack created the Women of OpenStack Working Group (which included educational sessions, professional networking, mentorship, social inclusion, and enhanced resource access), the OpenStack Foundation did not have baseline information about the involvement of women.

The literature also reports a diverse set of challenges being faced by women [PS13, PS18, PS20, PS21, PS22, PS23, PS24, PS25, PS26, PS27, PS28], many of them without associated strategies or further understanding. There is also no studies presenting theories to explain why how women leave or (not) join OSS projects. There are some studies about Manuscript submitted to ACM

motivations to participate in OSS projects [34, 38, 44, 50], but only a few of them report women's motivations and none go deep in this analysis. Moreover, the literature lacks research exploring why women leave OSS, their motivation to not participate in OSS, and why a large portion of women who study STEM do not join OSS projects.

Lastly, researchers can use this study's structure to investigate how the literature is positioned regarding the participation of other minority populations in OSS or even different domains.

Education: When knowing the challenges women face, educators can approach them in the classroom with students from all genders to improve awareness and discuss possible mitigation actions. This research can also inform educators who adopt OSS contributions to teach software engineering [66].

Future Women contributors: When undecided about their future career in IT, women can find the types of contribution made by other women in the present study. Although not restricted to the activities presented here, women can be inspired by other women's success and motivations to participate, gain awareness of the challenges reported by other women so they can prepare to face similar ones, and prioritize participation on projects that follow one or more reported strategies.

OSS communities: OSS communities that seek to foster gender diversity can combine and implement the strategies to increase women's participation, as we presented in the Discussion section. Moreover, when knowing the characteristics of women who contribute, the communities can target their efforts on them, for example, promoting events at universities (as most of the contributors are at least undergraduate students) and marketing actions focused on a public whose age range between 20-37.

6 RELATED STUDIES

Challenges faced by women in STEM. The gender gas52 is also present in the science, technology, engineering, and mathematics (STEM) fields at all education levels and in the labor market [26]. The barriers faced by women in STEM fields, presented by McCullough [53], are similar to some of the challenges we presented in Section 4.6, including discrimination and implicit bias (TOXIC CULTURE), lifestyle choices, and family obligations (WORK-LIFE BALANCE ISSUES), and lack of role models and mentors (COMMUNITY RECEPTION ISSUES).

Strategies to increase women's participation in STEM. The W-STEM project [33] seeks to create mechanisms to attract and guide women in Latin America in STEM higher education programs, including actions to keep measuring the gender equality in enrollment and retention (as we presented in the strategy PROMOTE AWARENESS OF THE PRESENCE OF PEERS). Another strategy proposed by both Garcia-Holgado et al. [33] and Moreno et al.'s [55] study is to disseminate scientific and technological culture from an early age, promoting STEM studies vocation and choice in girls and young women in secondary schools (as we presented in the strategy PROMOTE WOMEN-SPECIFIC GROUPS AND EVENTS). Moreover, the women who participated on Moreno et al.'s [55]'s study corroborated the strategy of PROMOTE INCLUSIVE LANGUAGE and the need to avoid chauvinistic attitudes, and to DE-STEREOTYPE the CS student, suggesting that the general image of the student majoring in CS should change and not ascribe to the nerd stereotype anymore. Some women may not want to be perceived as nerds, because the nerd stereotype is typically ascribed only to men.

There are also previous studies about women's participation in other cultures and domains. Analogous to OSS projects, women's barriers in the medical profession and their ability to rise to leadership positions are also influenced by social and cultural context [67]. In the opposite direction, women are active in war rebel groups where men are often presumed to be the default gender, and even are frequently involved in leadership roles [43]. By analyzing the career trajectories of women executives across a variety of sectors, Glass and Cook [35] concluded that while attaining promotion to leadership is not easy, serving in a high position can be even more challenging. Although Manuscript submitted to ACM

women can be more likely than men to be empowered to high-risk leadership positions, they often lack the support or authority to accomplish their strategic goals. As a result, women leaders often experience shorter tenures compared to men peers [35]. Similar to software development teams, where women are instrumental to reducing community smells [PS36], in international relations, the collaboration between women delegates and women civil society groups positively impacts and brings more durable peace when negotiating peace agreements [49]. The challenge of WORK-LIFE BALANCE that we presented in Section 4.5 is a general challenge faced by women who aim to work in Japan, where the low numbers of women in medicine reflect the prevalent societal belief that careers and motherhood do not mix [67]. In contrast, Scandinavia has similar numbers of men and women physicians, which has coincided with the emergence of progressive work–life policies, the belief that women can combine motherhood and employment, and changing expectations of work-life balance. Historically, Sweden was the first country to establish paid parental leave for fathers in 1974, and its National Labor Market Board has developed statements since 1977 encouraging men to contribute to childcare responsibilities [37].

To the best of our knowledge, there are no other studies aggregating evidence about women's participation in OSS projects. Considering that women are still underrepresented in OSS and projects seek more diversity to increase productivity and enhance the quality of delivered software, it is crucial to understand the profile of women who contribute to OSS, their motivations, challenges, and strategies to attract and retain them.

7 THREATS TO VALIDITY

We used the checklist provided by Ampatzogloua et al.[1] to identify and categorize threats to validity and corresponding mitigation actions.

Study inclusion/exclusion bias There may be relevant papers in the population that are not in our sampling frame, e.g., studies that covered women's participation in OSS published in outlets that are not indexed by the target search engines or excluded by the filters we used (see Section 2.1.2). Also, there may be relevant articles in the sampling frame that are not in the sample; for example, there may be papers covering women's participation in OSS never use the terms we included in the search string. We took several steps to mitigate these threats, including additional terms besides women in search string (e.g., diversity and heterogeneous team), backward and forward snowballing, having the list of primary studies reviewed by the most prolific authors.

Researcher bias and Repeatability We used an open research question (and search string) to find all kinds of women's participation in OSS. This openness can bring subjectivity to the data extraction and repeatability. While the first author of this study leaded the execution of steps to filter and select the primary studies (see Fig 2, other two researchers with extensive experience in conducting qualitative analysis and literature studies participated on defining the protocol with phases and steps (see Fig 1), inclusion and exclusion criteria, and discussed the data in weekly meetings during the recording process. Besides, one senior researcher cross-checked a portion of the extracted data. During the weekly meetings, we discussed and adjusted codes and categories until we reached agreement. In the meetings, we also checked the consistency of our interpretations.

Robustness of classification We used existent classification schema from literature to explain two categories of participation: the types of contributions that women make in OSS projects (see Section 4.3) and the motivations that drive women to participate in OSS projects (see Section 4.5). The selection of those two initial classification schema poses a threat, since they might not be enough to explain the phenomena its tailoring not efficient. At the same time that we had these schemas to guide our analysis, we constantly assessed the possibility and need of extending them. Therefore, although we did not find any new category of motivation to extend Von Krogh et al.'s [90] framework of Manuscript submitted to ACM

OSS motivations, we extended the classification used for types of contributions with new roles that arouse from the primary studies.

8 CONCLUSION

In this paper we investigated the women's participation in OSS projects, in terms of their participation's frequency, the demographics of women who contribute to OSS projects, the types of contributions women make, how well-succeeded they are being when contributing, their motivations to participate, the challenges they face and would influence them to leave OSS projects, and the strategies OSS communities can employ to help mitigating those challenges.

Our findings show that, according to the literature, women represent about 9.8% of Open Source Software contributors, considering different types of participation. The majority of women contribute to OSS projects for less than five years, devote less than one work-day to OSS on few repositories, and are at least undergraduate students. While being more present in community-centric roles, women are low represented as authors of pull-requests and as core developers, mostly making non-code contributions. When submitting a pull-request, women have high rates of merge acceptance, and lower when they explicitly identify themselves as women. Reciprocity, kinship and getting paid motivates more women than men. Altruism, learning, and own-use motivate both men and women, career and reputation are low-ranked for both genders. When contributing, women face social challenges such as a lack of peer parity, non-inclusive communication, a toxic culture, impostor syndrome, community reception issues, stereotyping, and work-life balance issues. OSS communities that seek to increase women's participation can mitigate those challenges by providing awareness about the presence of other women, promoting inclusive language, organizing women-specific groups and events, de-stereotyping the OSS contributor, encouraging and welcoming women, placing women in leadership, adopting de-biasing tools, recognizing women's achievement, preparing mentors to guide women, and creating and enforcing a code of conduct.

As future steps, we plan an in-depth analysis of women's motivations, challenges, reasons that would make them leave, sense of belonging to the community, and their perceptions of OSS communities' success. As a long-term plan, we will propose strategies to attract and retain more women to OSS communities.

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