

Research trends in free software development: a research agenda

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Abstract

The development of free software has attracted increasing academic interest, consolidating its status as a field of study characterised by substantial scientific production. This study, grounded in a systematic review of the extant literature employing the PRISMA 2020 methodology, aims to establish a comprehensive framework of knowledge in this domain and identify research gaps. The results demonstrate a sustained increase in the number of publications, with periods of greater activity linked to the adoption of collaborative models and the rise of platforms such as GitHub. A core of authors and institutions has been identified with a significant contribution to the theoretical development of free software, although with a geographical distribution concentrated in certain regions. Likewise, the most cited studies have been fundamental for the consolidation of methodological approaches and practical applications. The analysis of keywords highlights the centrality of collaboration in the free software ecosystem, reflecting a change in the dynamics of development and dissemination of knowledge. These findings emphasise the need to strengthen research around open models and their impact on industry, education and digital governance.

Keywords

Free software; collaboration; GitHub; scientific production; technological development

INTRODUCTION

Free software is distinguished by its capacity to permit unrestricted access, modification and distribution of its source code, in contrast to the limitations imposed by proprietary software. This characteristic fosters collaboration among developers, companies and academic communities, thereby promoting innovation and the dissemination of knowledge [1]. In the contemporary context, free software plays a pivotal role in enhancing accessibility and digital independence. Its application in operating systems, databases and artificial intelligence has reduced dependence on proprietary software and strengthened technological sovereignty in various countries and institutions [2]. Moreover, its collaborative development improves transparency, computer security and the detection of vulnerabilities, which are essential factors in the face of the growing complexity of the digital environment and cyber risks [3].

From an economic perspective, free software has modified technological production and distribution, promoting business models based on services, technical support and customisation [4]. Its adoption has grown in sectors such as finance, education and healthcare, consolidating itself as a viable and sustainable alternative [3]. Given its growth and its impact in multiple areas, it is necessary to examine the research trends in this field. The identification of predominant approaches will facilitate understanding of its evolution, thereby enabling the strengthening of its development as a scientific discipline and the generation of knowledge to guide future technological applications [5].

Free software has been the subject of multiple studies in the academic literature [6], [7], [8]. However, the absence of a clear structure within the scientific field makes it difficult to consolidate it as a defined field of study [9]. The variety of approaches and methodologies has generated a dispersion of knowledge, which prevents the precise identification of trends and patterns in existing research [10]. This situation limits the understanding of its evolution from a scientific perspective and makes it difficult to formulate new lines of study [10].

Notwithstanding the increase in academic production on free software, there is a paucity of studies that analyse its development in terms of volume of publications, influential authors, and distribution of knowledge at a global level. The absence of such analysis precludes a comprehensive view of the current state of the field, which hinders the identification of advances and pending challenges [9].

The absence of an articulated structure has a detrimental effect on the construction of a coherent research agenda and the identification of knowledge gaps, thus limiting the formulation of solid theoretical models and hindering the design of strategies to expand the impact of free software in technological and academic sectors [11], [12]

In addressing this gap, the objective of the research is to identify research trends in the development of free software through a systematic review of the literature. This analysis seeks to structure the scientific body of the field and recognise the existing knowledge gaps. To achieve the stated objective, there are a series of questions that guide the analysis of scientific production in free software:

RQ1: What has been the evolution of academic production in free software in terms of the number of publications per year?

RQ2: Who are the main authors and journals that have contributed to the development of knowledge in this field?

RQ3: What are the most cited studies and what has been their impact on the evolution of the field?

RQ4: How is scientific production on free software distributed globally in terms of countries and institutions?

RQ5: What are the emerging, growing and decreasing keywords in free software research?

This study provides a structured perspective on the scientific literature concerning free software, facilitating the identification of patterns in its development and evolution. Its contribution lies in the updating of knowledge through the detection of trends and research gaps, enabling the formulation of a coherent academic agenda oriented towards future opportunities. It also facilitates the recognition of emerging areas and strengthens the theoretical basis of the field, thereby promoting a more rigorous and systematic analysis.

Finally, it provides researchers and decision makers with the tools to understand the current state of knowledge and its potential evolution, which will favour a more informed and strategic development of free software in different areas.

METHODOLOGY

The PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology establishes a structured and transparent framework for the selection, evaluation and synthesis of scientific literature in systematic reviews [13]. Its application guarantees the reproducibility of the study, reduces bias and optimises the quality of evidence synthesis. In the context of the analysis of free software development, PRISMA 2020 facilitates the identification of trends, challenges and contributions documented in the academic literature, ensuring a rigorous selection process based on objective criteria that facilitate the attainment of accurate and representative findings.

Eligibility criteria

The selection of relevant studies on free software development was determined by the application of eligibility criteria. The definition of inclusion and exclusion criteria was informed by the objectives of the study. Documents were included if their title indicated an explicit relationship between software development and open distribution models, covering open source, shared or public domain software. Research addressing technical, methodological or impact aspects in the development of this type of software was prioritised.

The exclusion process was carried out in three phases. Firstly, poorly indexed documents that did not comply with the required thematic coherence were discarded. Secondly, the accessibility of the full texts was verified, and studies were not excluded at this stage, since the systematic review only analysed documents with full access. Thirdly, studies whose content was not aligned with the analysis objectives were eliminated, such as those focused on proprietary development models or contexts outside of free software.

Sources of information

The information sources employed in this research comprised two of the most internationally recognised scientific databases: Scopus and Web of Science. Scopus, managed by Elsevier, indexes a wide variety of peer-reviewed publications in multiple disciplines, providing citation metrics and bibliometric analysis tools. Web of Science, managed by Clarivate Analytics, specialises in indexing high-impact journals, ensuring strict quality control in scientific literature [14].

The selection of these databases is driven by the necessity to ensure the quality and relevance of the studies analysed, with both sources offering global coverage and structured access to research of high academic rigor, thereby ensuring a balanced representation of the knowledge available in the study area [14]. Their utilisation in systematic reviews guarantees that the selected documents are relevant and contribute significantly to the analysis of free software development.

Search strategy

The search strategy was defined based on the established inclusion criteria, ensuring the identification of relevant studies on free software development. To do this, a specific equation was designed for each database consulted, adapting its syntax to the corresponding operators.

In Scopus, the equation used was:

TITLE (develop*) AND TITLE ("Open Source Software" OR "Open-Source Software" OR "Shared source software" OR "Public domain software")

In Web of Science, the same equation was adjusted to the database syntax:

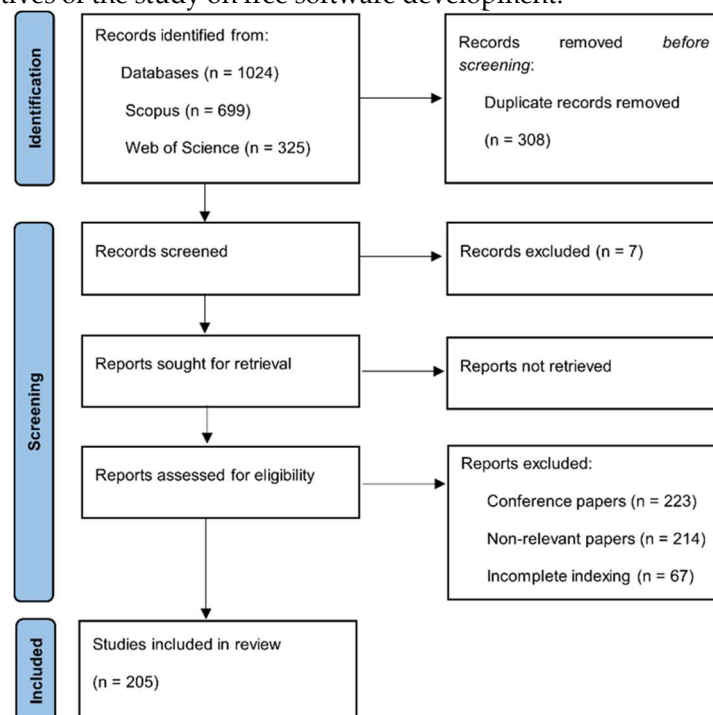
TI= (develop*) AND TI= ("Open Source Software" OR "Open-Source Software" OR "Shared source software" OR "Public domain software")

These equations allowed filtering documents whose title explicitly reflected software development and its relationship with open distribution models, thus ensuring that the selected studies met the inclusion criteria and were aligned with the research objectives.

Selection process

The document selection process was methodically executed, as illustrated in Figure 1. Initially, a search was conducted in Scopus and Web of Science, yielding a set of records. These records were then subjected to a preliminary exclusion based on indexing errors, followed by the removal of documents that were not fully accessible. It is noteworthy that no exclusions were recorded during this stage due to the unavailability of the full text.

In the final stage, the content of the remaining studies was reviewed to discard those that did not meet the inclusion criteria. This process was undertaken to ensure that the final set of documents relevant to the analysis met the objectives of the study on free software development.



Fig_1. PRISMA flowchart. Own elaboration based on Scopus and Web of Science

Data processing

The processing of data was chiefly conducted through the utilisation of Microsoft Excel as the primary instrument for the arrangement and examination of information. Subsequent to the selection of pertinent studies, the extraction of key metadata was undertaken, encompassing the title, authors, year of publication, source, and keywords.

Thereafter, the documents were categorised according to their focal point, distinguishing between theoretical studies, previous reviews, and practical applications in the realm of free software development. The employment of filters and dynamic tables facilitated the identification of patterns, trends, and relationships among the investigations. This methodological approach ensured the systematic structuring of the information, facilitating both quantitative and qualitative analysis of the collected data. Furthermore,

it ensured coherence in the interpretation of findings and the traceability of the selection criteria applied in the research.

Risk of bias

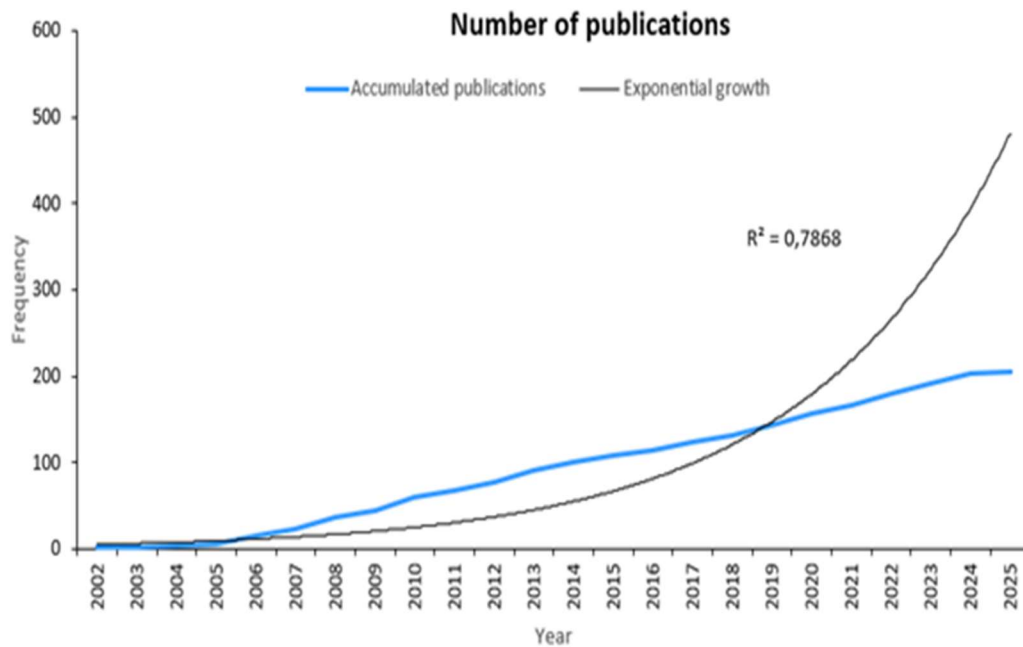
The risk of bias in the selection of studies was assessed considering possible limitations in the search strategy and in the availability of information. The choice of Scopus and Web of Science, although it guarantees quality and relevance, can introduce bias by excluding documents indexed in other databases.

Likewise, the use of specific terms in the search equations may have limited the recovery of relevant studies that used alternative names for free software development. Reporting bias is also a risk factor, since research with negative or less favourable results may not have been published, and this is a risk that needs to be mitigated. To this end, consistent selection criteria and a structured analysis process were applied to enable an exhaustive and objective review of the available literature.

RESULTS

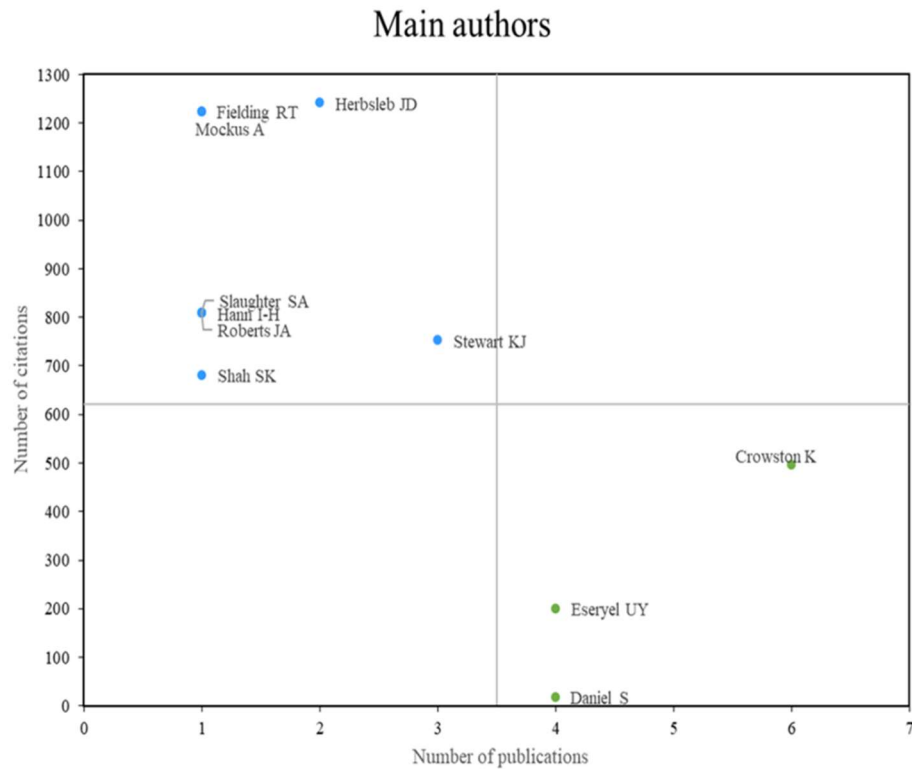
The scientific literature on free software development has its first records in 2002 and extends until 2025, showing an exponential growth of 78.68%, as seen in Figure 2. This increase reflects a sustained interest in the field, with a clearly upward trend in academic production. However, the fit of the growth model should be assessed based on the coefficient of determination (R^2), which indicates whether the relationship is strong or dispersed. Based on recent data, there is variability in the number of publications per year, which could suggest an average R^2 , reflecting positive overall growth, although with fluctuations in annual production.

Fig_2. Evolution of the number of publications



The analysis of the primary authors in the domain of free software research has enabled the identification of three distinct groups, as illustrated in Figure 3. The initial group, depicted in orange, pertains to the authors exhibiting the highest levels of impact in terms of citations and the number of publications. However, no researchers were identified within this category. Conversely, the secondary group, represented by the blue colour, is distinguished by a low number of publications, yet a substantially higher number of citations when compared to the average. This group includes the authors Herbsleb, Fielding and Mockus. Finally, the third group, represented in green, includes those researchers with high academic productivity, but with a low number of citations. Among these authors, Crowston, Eseryel and Daniel stand out.

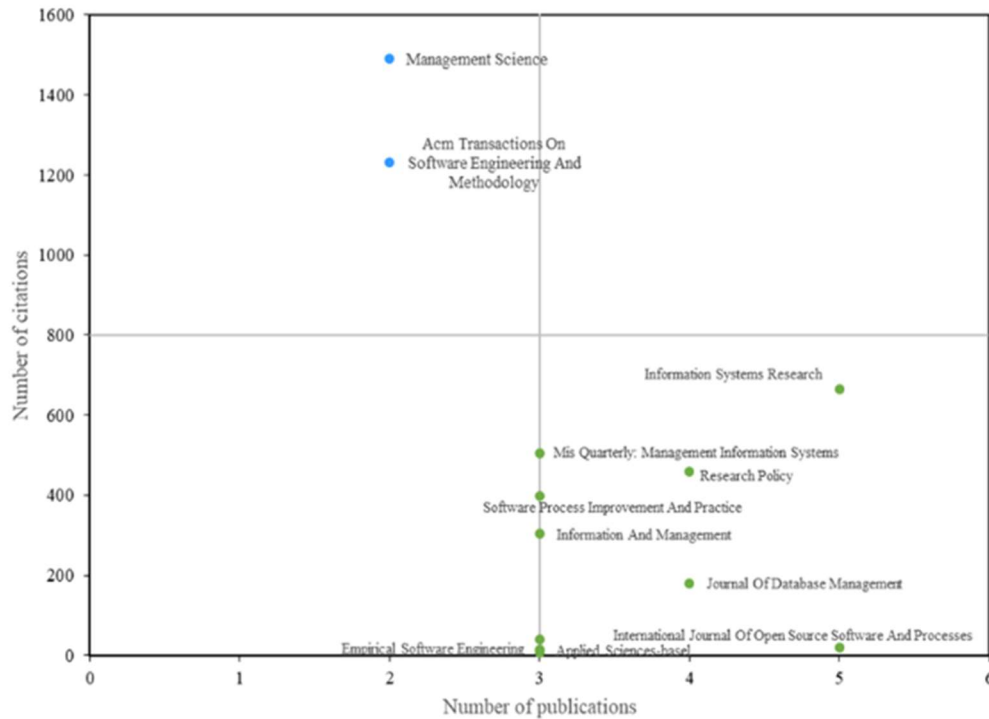
Fig_3. Main authors



The analysis of the main journals in free software research has allowed us to identify three distinct groups, as shown in Figure 4. The first group, represented in orange, corresponds to the journals with the greatest impact in terms of citations and number of publications; however, no journals were identified in this category. In contrast, the second group, in blue, groups those journals with a low number of publications, but with a volume of citations significantly higher than the average. Management Sciences is included in this group. Finally, the third group, represented in green, includes journals with high academic productivity, but with a low number of citations. Information Systems Research is distinguished within this group.

Fig. 4. Main journals

Main journals



An analysis of the ten most cited articles in the domain of free software research illuminates the seminal contributions to the development and understanding of the phenomenon, as delineated in Table 1. The most cited study, 'Two case studies of open source software development: Apache and Mozilla' by Mockus et al. [15], has garnered an impressive 1,225 citations, followed by 'Understanding the motivations, participation, and performance of open source software developers: A longitudinal study of the Apache projects' by Roberts et al. [16] has received 809 citations, while other notable works include research on governance in free software [17], ideological impact on development teams [18], and the development of open source tools in various fields. These studies reflect the evolution of the field and its impact on different disciplines.

Table 1. Main contributions in the literature

Title	Authors	Citations
Two case studies of open source software development: Apache and Mozilla	[15]	1225
Understanding the motivations, participation, and performance of open source software developers: A longitudinal study of the Apache projects	[16]	809
Motivation, governance, and the viability of hybrid forms in open source software development	[17]	682
The impact of ideology on effectiveness in open source software development teams	[18]	482
Development of a novel CASA system based on open source software for	[30]	357

characterization of zebrafish sperm motility parameters		
A new open-source software developed for numerical simulations using discrete modeling methods	[31]	292
Development of the OpenQuake engine, the Global Earthquake Model's open-source software for seismic risk assessment	[32]	290
Impacts of license choice and organizational sponsorship on user interest and development activity in open source software projects	[33]	235
Information systems success in free and open source software development: Theory and measures	[20]	235
Emergence of new project teams from open source software developer networks: Impact of prior collaboration ties	[34]	231

The analysis of the global distribution of research on free software has allowed the identification of the countries with the greatest academic production in the area (see Figure 5). The United States leads significantly with 57 publications, consolidating itself as the main generator of knowledge in the field. The second-largest contributor is China, with 12 publications, followed by India (9), and several European nations, including France (6), Germany (6), Switzerland (5), Italy (5), the United Kingdom (4), and the Netherlands (4). Japan also stands out with 6 publications.

Fig. 5. Global distribution

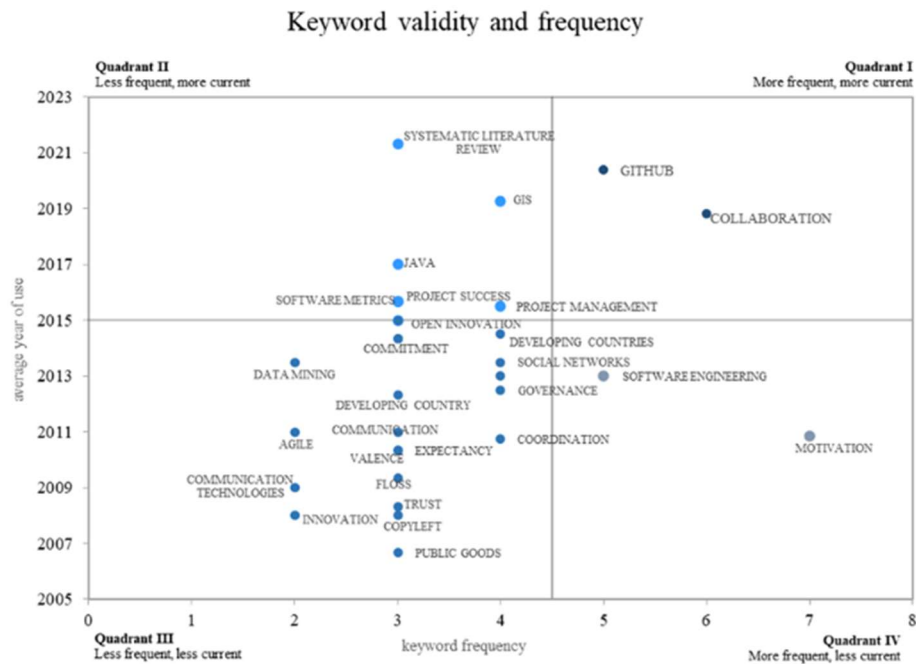


From a continental perspective, the United States is positioned as the region with the highest production, thanks to its leadership in the field. In Asia, China, India and Japan show a prominent participation, reflecting the growing interest in the technological development of the region. Europe, meanwhile, presents a significant and diversified contribution, with France, Germany, Switzerland, Italy, the United Kingdom

and the Netherlands as key players in the generation of knowledge on free software. This distribution demonstrates a concentration of research development in economies with a strong technological and institutional base.

The analysis of the keywords in the research on free software, as illustrated in Figure 6, is based on a scatter graph in which the Y axis indicates the average year of use and the X axis shows the frequency of appearance. This approach enables the identification of three main categories: in the first quadrant are the growing words, which have been widely researched and whose use is recent, indicating their relevance today. The second quadrant groups emerging concepts, which, although they have a lower frequency of use, present a recent average year of appearance, suggesting that they could become trends in the future. Finally, the fourth quadrant positions decreasing concepts, that is, terms that have been frequently researched, but whose average use is no longer recent, indicating a possible loss of interest in the scientific community.

Figure 6. Main keywords



Specifically, the first quadrant includes growing keywords such as Collaboration and Github, which reflect the interest in collaborative work models and shared development platforms. In the second quadrant, corresponding to emerging concepts, there are Systematic Literature Review, GIS and Java, which suggests a boom in methodological studies and geospatial applications within free software. Finally, in the fourth quadrant, which groups the declining concepts, terms such as Motivation and Software Engineering stand out, which, although they were widely researched in the past, have decreased in relevance in recent studies.

DISCUSSION

The ensuing discourse is methodically organised into distinct sections, with the primary objective being to facilitate a thorough examination of the findings. Initially, the results are subjected to a critical scrutiny and meticulously structured into a conceptual framework that encapsulates the predominant trends in research on free software development. Subsequently, a comparative analysis is conducted between these results and those of preceding studies, with the aim of identifying both commonalities and discrepancies, in addition to ascertaining the contributions made by each study. Thereafter, research gaps are analysed to highlight unexplored areas and to propose potential future directions. Based on these identified gaps and prevailing trends, a research agenda is proposed with the objective of providing a framework to guide future studies.

Finally, the theoretical, policy, and practical implications of the findings are presented, along with the methodological and empirical limitations of the study, to define its scope and suggest improvements in future research.

Analysis of results

The development of scientific research in the domain of free software has demonstrated a consistent growth trajectory since 2002, though with periodic fluctuations in its annual output, indicating a degree of variability in the field's consolidation. In its initial stages, research conducted by Mockus, Fielding and Herbsleb [15] centred on the comparison of open and commercial models, assessing factors such as productivity and code quality. However, as time has passed, there has been a shift in focus towards social and ethical issues, as demonstrated by the recent work of Fan et al. [19] on the impact of protestware. This shift indicates a diversification of theoretical approaches and an integration of political and governance aspects in the academic discussion.

Conversely, an analysis of the primary authors in research on free software suggests a tension between productivity and impact. Researchers such as Herbsleb, Fielding and Mockus, with a lower volume of publications but high citation, have been fundamental to understanding collaborative development in open communities [15]. In contrast, authors such as Crowston, with a broader production but less individual impact, have addressed the success of FLOSS projects from structural and organisational perspectives [20]. This dichotomy illustrates a transition from the study of development processes to the analysis of their impact on the organisational and social ecosystem.

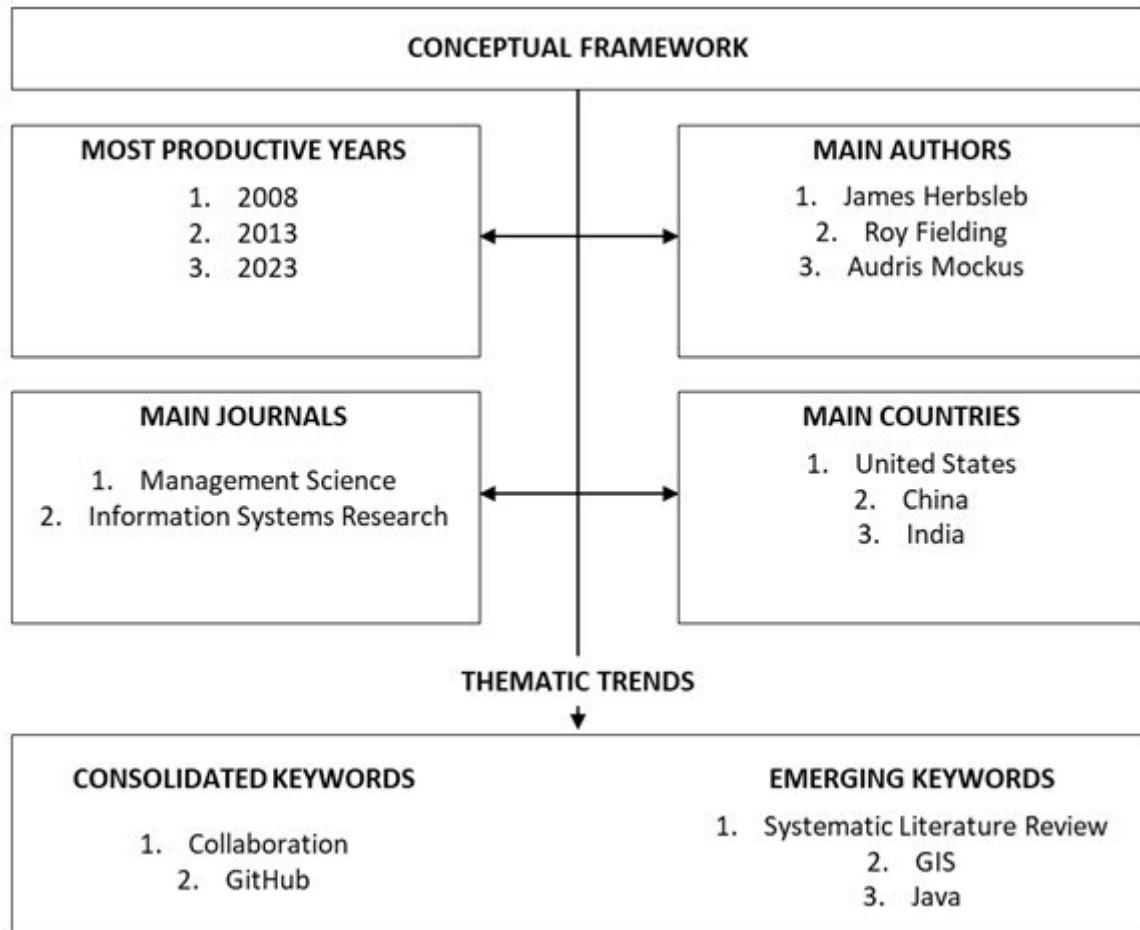
Conversely, journals that publish on free software demonstrate a discrepancy between impact and productivity. Management Science, with a reduced volume of articles but elevated citations, has featured seminal studies such as that of Roberts, Hann and Slaughter [16] on developer motivations and performance. Conversely, Information Systems Research, despite having a greater number of publications, but with a lower impact in citations, has explored the participation of peripheral developers and their influence on the quality of free software [21]. This distinction suggests that research on free software has not only diversified thematically, but has also found niches of dissemination with different levels of specialisation and influence. With regard to the impact of the most cited articles, the importance of complementary approaches is observed. While Mockus et al. [15] established the empirical foundations for evaluating the competitiveness of free software against commercial models, Roberts et al. [16] delved deeper into the motivational factors that drive participation in these projects. Consequently, the coexistence of these approaches underscores the necessity to consider both technical and human aspects in the evolution of free software.

From a geographical perspective, the leadership of the United States in free software research is evident in studies such as that of Taylor and Sheikh [22], who explore the impact of open source on health innovation, and that of David and Shapiro [23], who analyse the dynamics of participation in FLOSS communities. In this sense, the intersection between individual motivations and technological advances serves to consolidate the role of the United States as the epicentre of knowledge in free software, although it also raises questions about the decentralisation of the field and the prominence of other regions.

Finally, the keyword analysis reveals the evolution of free software towards collaborative models and more structured methodologies. The growth of terms such as "Collaboration" and "GitHub" is indicative of the centrality of social platforms in free software development [24]. Conversely, the rise of "Systematic Literature Review" suggests a growing interest in scientific rigour [25]. This trend ultimately reflects a shift towards more analytical approaches and a greater concern for empirical validation within the field.

As illustrated in Figure 7, a consolidated framework has been developed to summarise and synthesise the key findings of the research. This scheme integrates the key dimensions identified in the analysis, thereby facilitating the structured visualisation of the relationships between the factors studied. This representation not only enables the interpretation of the results but also provides a conceptual foundation for future research and practical applications in this field.

Figure 7. Framework of the scientific body



Comparison with other studies

This research on the development of free software has enabled the identification of patterns in scientific production, with authors, journals and countries grouped based on their impact and productivity. A comparison of these results with those of previous studies reveals both methodological and conceptual similarities and differences. From a perspective of collaboration and community dynamics, Scacchi's study [26] analyses work practices, development processes and socio-technical networks within free software. This approach is complementary to the present research, since while Scacchi examines the organisational and social structure of FOSS (Free and Open Source Software) projects, the present study focuses on the structure of academic production. However, both studies agree on the relevance of collaboration and the impact of certain key actors within the free software ecosystem.

In terms of the impact on industry and education, the studies by Fedosov, Markushevich and Gubina [27], and Duan and Lee [28] analyse the development and application of free software in educational contexts. While the present research identifies the leading countries in scientific production on free software, these studies highlight the lack of development and application in certain regions, particularly in the educational sector. A convergence of views is observed in the identification of regional inequalities, although the present study focuses on academic distribution and not on the practical implementation of free software.

In contrast, Ahmad's work [29] introduces a theoretical debate on the nature of free software, contrasting the libertarian perspective with the corporate vision. This theoretical dichotomy complements the findings of the present study, since the distribution of authors and journals identified could be influenced by these

ideological currents. However, the present research does not directly address the impact of these visions on academic production.

Finally, it is observed that the classification of keywords in this research provides a novel approach in the identification of emerging and declining trends in the study of free software, extending the findings of previous studies by offering a temporal perspective on the evolution of research topics in the academic community.

Research gaps

In this regard, Table 2 is presented, which identifies the main gaps for future research along with their respective research questions. This table allows the structuring of future lines of inquiry that address under-explored aspects of free software development, such as the impact of new platforms, changes in business models or their adoption in specific contexts. In this way, a basis is provided for the construction of knowledge in the area and the orientation of subsequent studies. The study confirms some patterns previously identified in the literature, but also introduces new approaches in the bibliometric analysis of free software, providing a structural view of scientific production in the area.

Table 2. Research gaps

Category	Gap	Future research question
Business models	Impact on monetization	How can hybrid business models improve the sustainability of free software?
Sectoral adoption	Use in specialized industries	What factors influence the adoption of free software in highly regulated sectors such as healthcare or banking?
Innovation	Integration with AI	How can free software adapt to the growing integration with artificial intelligence and machine learning?
Governance	Decentralization in projects	What impact does decentralization have on the sustainability and evolution of free software communities?
Security	Vulnerabilities and mitigation	How can effective strategies be developed to improve security in free software projects without compromising their openness?
Education	Incorporation into curricula	What is the effectiveness of teaching free software development in engineering and computing academic programs?
Platform	New emerging architectures	How does the adoption of architectures such as edge computing affect the development of free software?
Community	Taxpayer retention	What strategies can be implemented to improve developer

		retention in free software communities?
Ethics	Licensing conflicts	How can ethical and legal conflicts arising from hybrid licenses in FOSS projects be resolved?
Accessibility	Inclusion of users with disabilities	What methodologies can improve accessibility in free software without compromising its flexibility?

Research agenda

The study of trends and gaps in free software research allows outlining a research agenda that responds to current and future challenges in the field. Based on the analysis of keywords (Figure 6), lines of research are identified that must be strengthened to maintain the relevance of studies in the discipline.

A primary research trajectory focuses on collaborative work models, with a particular emphasis on platforms such as Github, given their growing relevance. This necessitates the investigation of the impact of these tools on the evolution of free software, the distribution of responsibilities between developers, and the dynamics of contribution in projects of different scales. This encompasses not only studies on the effectiveness and sustainability of these models, but also their impact on the quality of the software produced and the retention of collaborators.

In the methodological domain, the emergence of the Systematic Literature Review in the second quadrant signifies a shift towards more rigorous and structured research approaches in the field of free software. However, it is imperative to explore the integration of mixed methodologies, encompassing bibliometric analysis in conjunction with qualitative studies on development communities and specific implementation cases. The enhancement of methodological rigor will facilitate the generation of a more consolidated and replicable body of knowledge, thereby preventing the fragmentation of the field.

The integration of Geographic Information Systems (GIS) into the realm of free software research has initiated a novel interdisciplinary field of enquiry, merging the disciplines of geoinformatics and free software. While free software applications in geographic information systems have demonstrated their viability as an alternative to proprietary solutions, questions persist regarding their adoption in critical sectors such as urban planning, natural resource management and disaster resilience. A comprehensive analysis of the interoperability and technical impediments of these systems is imperative to consolidate their position in these domains.

Conversely, the emergence of Java as a developing concept signifies a resurgence of interest in particular programming languages within the free software ecosystem. This opens up a line of research oriented towards the evolution of open source development tools, their compatibility with trends such as cloud computing and their relationship with software security. The exploration of emerging frameworks within the free ecosystem, as well as their comparison with commercial alternatives, will facilitate an understanding of the factors that influence their adoption and long-term sustainability.

Conversely, the waning interest in terms such as 'Motivation' and 'Software Engineering' indicates that certain conventional research strands have diminished in significance within the field. Nevertheless, this does not signify their irrelevance; rather, it suggests a necessity for a re-examination of their theoretical frameworks. The motivation of developers in free software projects, for instance, could be assessed from more contemporary vantage points such as behavioural economics or gamification, as opposed to conventional incentive models. Likewise, the application of software engineering to free development

stands to benefit from more dynamic approaches that consider agile methodologies and emerging paradigms in software architecture.

Finally, a research agenda on free software must consider its impact on digital transformation and its role within open access policies. The growing pressure for technological sovereignty in different regions and the adoption of free software in government institutions are phenomena that require greater attention. In this regard, it is imperative to analyse the relationship between free software and innovation in public policies, as well as the necessary conditions for these models to be scalable and sustainable in high-impact environments.

Implications

The findings of this research make a substantial contribution to the theoretical development of free software by highlighting the conceptual and methodological evolution of the field. The identification of emerging trends, as well as the transition in the predominant approaches, suggests the need to update the theoretical frameworks used to analyse the phenomenon. Until now, much of the literature has been dominated by models that emphasise collaboration, developer motivation, and software engineering in open environments.

However, the findings indicate that these approaches may be reaching an obsolescence, or at the very least necessitating re-evaluation through novel perspectives that take into account the intricacies of the contemporary ecosystem. The consolidation of platforms such as Github and the emergence of more structured methodologies, including systematic literature reviews, point to a shift in the field towards a phase of theoretical maturation, where the challenge of conceptual fragmentation must be addressed through integrative models and interdisciplinary approaches.

From a political perspective, the results of this study directly impact the debate on licensing, adoption, and regulation of free software. Despite the apparent consolidation of open source licenses, the decline in interest in concepts such as "software engineering" and "motivation" suggests that traditional models of free software governance may be losing their effectiveness.

The promotion of open source software in government and educational institutions has prompted the need for a re-evaluation of existing policies. This is due to the emergence of challenges such as interoperability with proprietary systems, reliance on commercial platforms, and the absence of incentives for the sustainable development of open source projects. Furthermore, the proliferation of collaborative tools based on centralized repositories has given rise to questions concerning decentralization and technological sovereignty. These issues must be given due consideration when formulating regulations that seek to balance openness with economic viability and digital security.

From a practical standpoint, these developments hold particular significance for industry, development communities, and regulatory bodies. For companies, the proliferation of concepts such as GIS and Java signifies strategic opportunities for the integration of free software-based solutions in critical sectors such as geoinformatics and business application development. Conversely, the decline in terms such as "motivation" points to a potential weakening of the contributor ecosystem, which poses a risk to the sustainability of numerous open source projects.

In order to ensure the continued viability of free software as an alternative to technological monopolies, regulatory bodies must update their licensing policies to facilitate the adoption of free software while maintaining autonomy. In order to maintain their competitiveness in a commercial environment, development communities must rethink their strategies for attracting and retaining talent, considering factors such as gamification, economic incentives and compatibility with commercial environments.

Limitations

Whilst the present research provides a detailed overview of free software development, there are certain methodological limitations that must be considered. Firstly, the temporal scope of the data analysed may

not capture emerging dynamics or recent changes in the field. Secondly, the selection of sources and the reliance on specific databases may introduce biases in the collection of information, limiting the representativeness of the findings. Likewise, the lack of qualitative approaches prevents a deeper understanding of the motivations and barriers to the adoption of free software. To obtain a more comprehensive understanding of the phenomenon, future studies should extend the period of analysis, diversify the data sources, and combine quantitative and qualitative methodologies.

CONCLUSIONS

A close analysis of academic publications pertaining to free software reveals a marked increase in the number of publications over time. This phenomenon is concomitant with periods of heightened activity, which are often associated with technological advancements and alterations in open access policies. This observation suggests a consolidation of free software as a pertinent field of study within the academic community.

Furthermore, an analysis of the most prolific authors and specialised journals underscores the existence of a cohesive group of researchers who have been instrumental in shaping the body of knowledge in this domain. The analysis of publication patterns reveals the emergence of specialized forums that serve as conduits for scientific production in the domain of free software, thereby promoting specialization and the development of novel theoretical and methodological perspectives.

In terms of impact, the most cited studies have made substantial contributions to the evolution of the field, either by providing foundational theoretical frameworks, exhaustive reviews, or empirical developments that have facilitated the validation and application of free software in diverse contexts. This analysis enables the identification of the most influential approaches and their role in shaping the direction of research.

The geographical distribution of scientific production reflects the relevance of free software in various regions, with a notable concentration in countries implementing open innovation policies and in institutions specialising in emerging technologies. This suggests the presence of a global research ecosystem, where certain countries and institutions function as nexus points in the generation of knowledge.

Finally, the analysis of keywords enables the identification of both emerging and declining trends within the domain of free software research. The consolidation of terms associated with artificial intelligence, security and interoperability is observed, suggesting an evolution of the field towards integration with other key technological domains. Concurrently, the decrease in certain terms reflects changes in research priorities and the displacement of approaches that have lost relevance in the face of novel problems and challenges.

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