Understanding Sustainable Growth in Industrial Open Source Software Through Collaboration Networks

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Digital Object Identifier 10.1109/MC.2026.3662832
Date of current version: 27 March 2026

This article examines the evolutionary dynamics of the FreeCAD ecosystem by combining longitudinal OpenRank measurements with multidimensional collaboration network analysis, revealing a co-evolutionary pattern that supports sustained ecosystem growth.

Open source software (OSS) has become a core component of modern digital infrastructure. In domains, such as operating systems, web platforms, and cloud-native

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FROM THE EDITOR

Welcome back to our column on open source software and how it is changing the world! This time, we let science take a look at the FreeCAD open source software and ecosystem by way of how people collaborate. Not surprisingly, this open source project, like many, coevolves technical need with project management and governance needs in order to grow and prosper. And so it does! And by this, it may provide inspiration and practices to other open source projects to do the same. Stay happy and healthy.
—Dirk Riehle

systems, OSS is widely adopted as the default development and deployment model.[1] Industrial software, by contrast, including computer-aided design (CAD), multiphysics simulation, and manufacturing automation, has historically evolved more conservatively. These systems are subject to strict requirements for numerical robustness, deterministic execution, compatibility with legacy workflows, and long-term maintenance, which has traditionally favored proprietary and vendor-controlled toolchains.

In recent years, this situation has begun to change. The acceleration of industrial digitalization and Industry 4.0 initiatives, together with increased emphasis on interoperability and long-term sustainability, has exposed practical limitations of closed-source ecosystems. Vendor lock-in, limited extensibility, and dependency on single suppliers have become concrete concerns for engineering organizations. Against this backdrop, industrial OSS has gained renewed attention. Projects, such as OpenFOAM, OpenModelica, and ROS-Industrial, demonstrate that open source development models can meet industrial reliability and performance requirements. At the same time, their development outcomes differ markedly. Some projects achieve technical maturity but remain confined to specialized user groups, while others, including FreeCAD, have recently shown sustained growth in contributor activity, ecosystem integration, and professional adoption.[2]

This divergence points to a practical issue faced by many industrial OSS projects. Technical capability is a necessary foundation, but it does not by itself explain why some projects scale into widely used platforms while others plateau. Observations from multiple industrial OSS initiatives suggest that growth is closely tied to the presence of stable governance structures, predictable release and maintenance processes, and mechanisms that support coordinated contributions at scale.

This article examines these factors through the evolution of FreeCAD. It focuses on concrete developments in the project over time, including key architectural decisions, the organization of contributor communities, and the establishment of formal governance structures. Drawing on publicly available collaboration data and documented project milestones, the article seeks to elucidate how an industrial open source project can evolve from a community-driven tool into a sustainable engineering platform.

OpenRank

To characterize the growth and activity of the FreeCAD ecosystem, this article uses OpenRank[3,4] as a high-level indicator derived from observable open source collaboration signals. These signals include issue activity, pull request submissions, code reviews, and other forms of developer participation recorded on public platforms, such as GitHub. Rather than measuring software quality or end-user adoption directly, OpenRank reflects the intensity and continuity of collaborative activity around a project, which practitioners often recognize as a leading indicator of ecosystem health.

At a conceptual level, OpenRank aggregates interactions between developers and repositories into a single influence score. Higher values indicate sustained engagement from a broader and more interconnected contributor base, while lower values typically correspond to sporadic or concentrated activity. In practice, this makes OpenRank useful for comparing relative changes over time within the same project, rather than for making absolute judgments across unrelated projects.

For this article, publicly available GitHub collaboration data related to FreeCAD were collected for the period from 2015 to 2025. Annual snapshots of collaboration activity were used to observe how contributor participation and interaction density evolved over time. The resulting OpenRank values are therefore interpreted as a longitudinal signal of ecosystem momentum, rather than as a precise or exhaustive measurement.

It is important to note that OpenRank captures only one aspect of an open source project. It does not account for offline adoption, commercial deployments, or internal usage within organizations. Nevertheless, when combined with documented project milestones and governance developments, it provides a useful, reproducible view of how collaborative activity around FreeCAD changed as the project matured.

OSGraph

To examine how collaboration around FreeCAD evolved at scale, this article draws on OSGraph,[5] an open source ecosystem data platform built from

large volumes of publicly available collaboration records. At the time of analysis, OSGraph contained more than 5.8 billion graph records covering developers, repositories, and their interactions across major open source platforms.

OSGraph makes it possible to view an open source project from multiple structural perspectives rather than through a single activity metric. In the case of FreeCAD, it was used to observe three complementary aspects of the ecosystem: patterns of contribution within the core project, interactions with upstream and downstream dependencies, and the composition of the contributor community. Together, these views help illustrate how individual technical contributions aggregate into a broader ecosystem and how that ecosystem changes as a project matures.

GROWTH TRAJECTORY OF THE FREECAD ECOSYSTEM

The evolution of the FreeCAD ecosystem between 2015 and 2025 shows a clear shift in both scale and character. As illustrated in Figure 1, collaboration activity around the project progressed from steady growth to sustained acceleration. When viewed alongside documented technical and organizational milestones, this trajectory reveals how FreeCAD moved from a niche open source CAD tool toward a broadly adopted industrial platform.

From early consolidation to sustained growth

Between 2015 and 2017, FreeCAD experienced its first phase of visible consolidation. During this period, ecosystem activity increased from a very low baseline, with OpenRank rising from 20.78 to 391.47. This growth coincided with the emergence of a stable core contributor group and the continued refinement of the modular workbench architecture. This phase reflects a common early-stage pattern: adoption remains limited, but architectural decisions begin to reduce barriers for external contributions and extensions.

From 2018 to 2021, growth became less linear. Activity levels showed temporary stagnation before recovering steadily. This period corresponded to intensive internal work on long-standing technical issues, including major refactoring efforts, migration to Python 3 and Qt 5, and incremental progress on the *topological naming problem*. Although these changes did not immediately translate into visible ecosystem expansion, they significantly improved system stability and maintainability. This phase illustrates the cost of addressing technical debt in mature engineering software, where short-term disruption is often the price of long-term scalability.

A distinct change occurred after 2022. Ecosystem activity increased rapidly, with OpenRank rising from 940.24 to 3,156.39 by 2025. Unlike earlier phases, this acceleration aligned with organizational and institutional developments rather than purely technical ones. The establishment and operational maturation of the FreeCAD Project Association (FPA) enabled more predictable coordination, funding mechanisms, and release processes. At the same time, increased involvement from commercial actors, such as Ondsel, and the visibility associated with the v1.0 release cycle expanded FreeCAD's presence in professional engineering contexts. Together, these factors transformed earlier technical readiness into sustained ecosystem momentum.

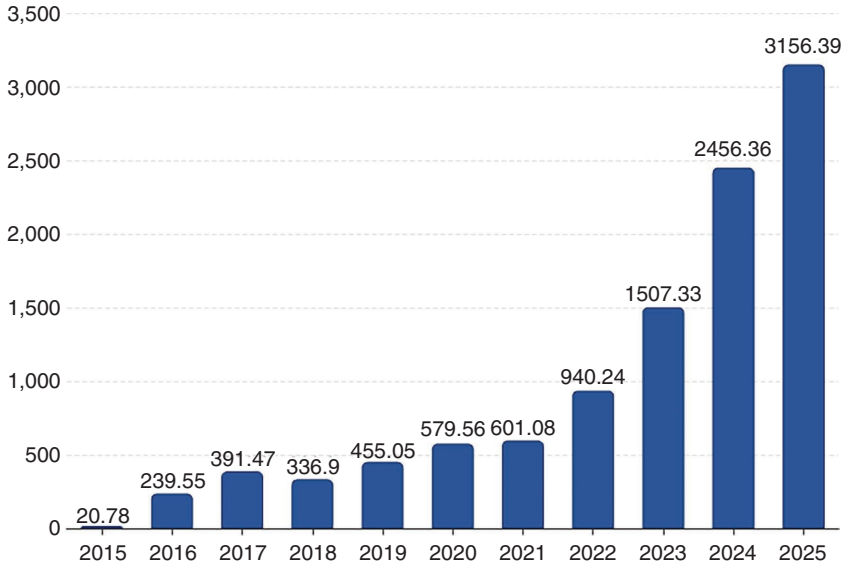

Figure 1. OpenRank trend of FreeCAD (2015–2025).

Collaboration structures at different scales

Beyond overall growth, the structure of collaboration around FreeCAD also evolved in observable ways. Using ecosystem-level views derived from OSGraph, three complementary collaboration layers can be distinguished, as shown in Figure 2(a)–(c).

At the project level, contribution patterns gradually shifted toward a more structured review and integration process. In addition to code submissions, coordination around pull requests and code reviews became more centralized, especially during preparation for the v1.0 milestone. This helped ensure that architectural changes were applied consistently across modular workbenches.

At the ecosystem level, FreeCAD increasingly functioned as a central integration point within the open source engineering toolchain. Its interactions with upstream dependencies, such as

OpenCASCADE and Coin3D as well as downstream tools, including KiCad and various building information modeling (BIM)-related workbenches, became denser over time. This pattern reflects a shift from isolated application development toward coordinated ecosystem participation.

At the community level, participation diversified beyond individual contributors. Organizational involvement increased, including the FPA, commercial vendors, and engineering consultancies. This change reduced reliance on a small number of individuals and improved the project's resilience to contributor turnover, which is particularly important for long-term industrial adoption.

Technical maturity as an enabling condition

Technical evolution provided the necessary foundation for FreeCAD's expansion, but it did not, by itself, drive ecosystem growth. Early integration of the Open CASCADE Technology kernel established a solid parametric modeling core, while the modular workbench architecture allowed domain-specific functionality, such as BIM, finite element method, and computer-aided manufacturing to evolve independently.

Over time, several long-standing bottlenecks were addressed. The introduction of a centralized add-on manager simplified extension distribution, and the transition to modern toolchains improved maintainability. The v1.0 release cycle, which began in late 2024, marked the culmination of these efforts. In particular, the integration of a comprehensive approach to the *topological naming problem* removed a critical obstacle for professional use. These improvements functioned as an enabling threshold. They made industrial

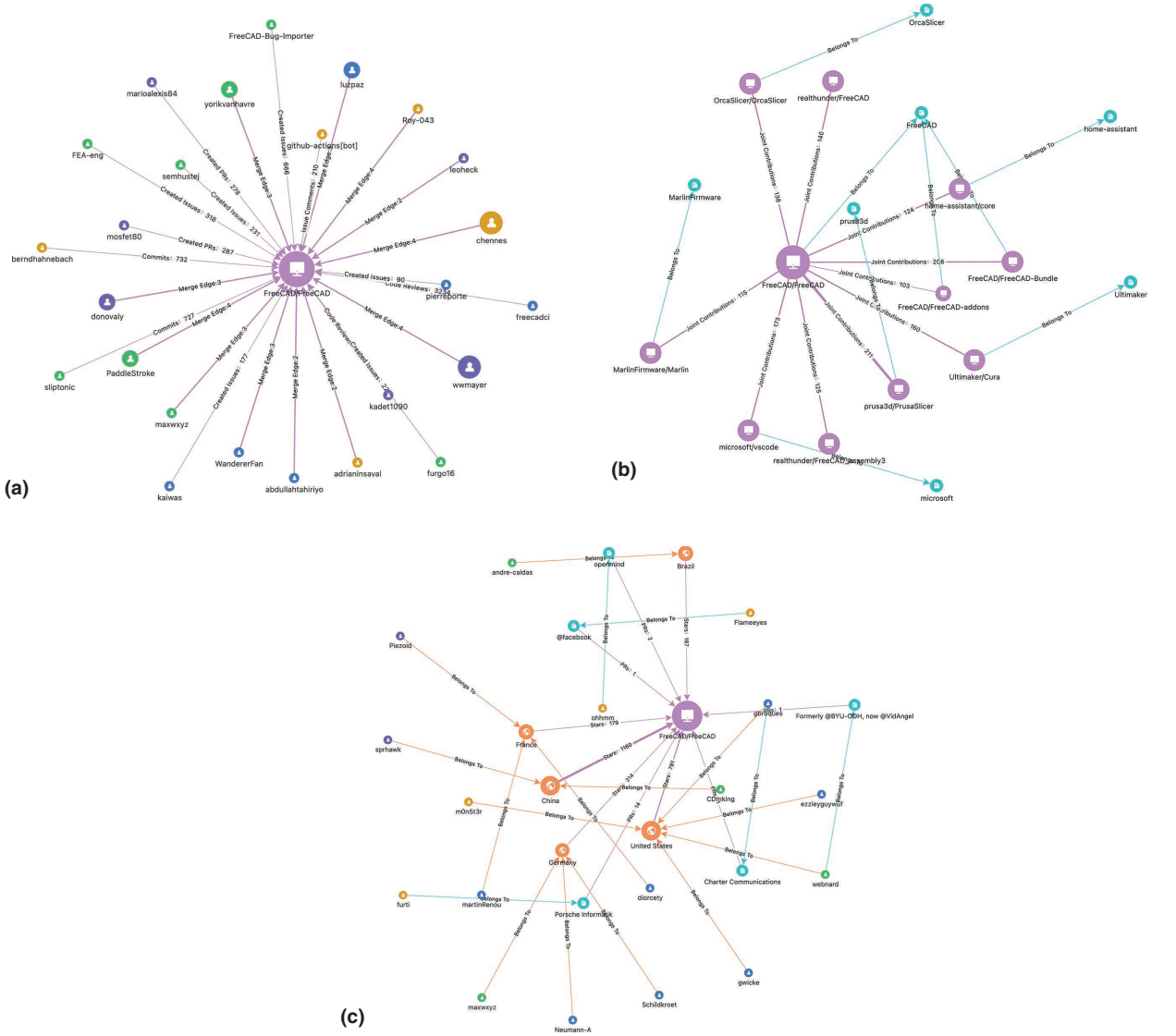

Figure 2. Collaboration structures in the FreeCAD ecosystem. (a) Project contribution. (b) Ecosystem integration. (c) Community structure.

adoption feasible, but they did not automatically produce growth. The subsequent acceleration observed after 2022 suggests that it was the combination of technical readiness with governance structures and organized community support that ultimately converted technical capability into sustained ecosystem expansion.

GOVERNANCE INSTITUTIONALIZATION

From informal coordination to formal governance

For a substantial period of its development, FreeCAD relied on a highly decentralized and informal governance arrangement. Project coordination was primarily driven by volunteer contributors and ad hoc consensus, which proved effective in supporting early experimentation and incremental feature development. However, this mode of governance offered limited capacity for managing financial resources, intellectual property, or long-term strategic planning, all of which are critical for industrial adoption.

A structural transition occurred in 2022 with the legal incorporation of the FPA. The establishment of the FPA marked a shift from purely informal coordination toward an organizational form capable of engaging with external institutions. Through legal incorporation, the project obtained the ability to manage funds, enter contractual relationships, and represent the project in interactions with corporate and public stakeholders. In addition, the introduction of documented governance procedures clarified decision-making authority and responsibility, reducing ambiguity in leadership and project direction.

Governance as an enabling infrastructure

The formalization of governance coincided with observable changes in development capacity and ecosystem engagement. The FPA enabled the allocation of financial resources to targeted development efforts, including developer grants and maintenance activities. This support contributed to more predictable release processes and improved maintenance continuity, factors that are particularly relevant for industrial users who depend on stable software lifecycles.

Moreover, the presence of a recognized governing body facilitated interaction with commercial entities and service providers, including companies, such as Ondsel. Rather than replacing community-driven development, these relationships introduced additional channels for professional support and long-term sustainability. From an ecosystem perspective, the institutional legitimacy provided by the FPA lowered participation barriers for organizations that require clear legal and governance structures before committing resources. This transition temporally aligns with the increase in OpenRank values observed after 2022.

Architectural modularity

FreeCAD's governance evolution was closely intertwined with its technical architecture. The workbench-based modular design allowed contributors to focus on domain-specific functionality without requiring centralized coordination across the entire codebase. This modularity supported the coexistence of multiple sub-communities, such as those centered on mechanical design, architecture, and digital fabrication, while limiting coordination overhead.

In parallel, structured participation mechanisms, including involvement in programs, such as Google Summer of Code, provided a recurring entry point for new contributors. The expansion of localized documentation and language-specific community forums further broadened the contributor and user base. As a result, participation in the FreeCAD ecosystem spans a wide range of backgrounds, including academic researchers, independent developers, and industrial practitioners, reducing dependency on any single contributor group.

Feedback dynamics between governance and community growth

The interaction between institutional governance and community participation exhibits characteristics of a reinforcing dynamic. Improved governance capacity enhanced project stability and external credibility, which in turn attracted contributors with more complex requirements and professional use cases. These contributions fed back into technical refinement and documentation quality, strengthening the overall ecosystem.

Rather than exhibiting stagnation commonly associated with long-lived open source projects, FreeCAD demonstrates continued growth across multiple dimensions, including contributor diversity, organizational participation, and collaborative intensity. The available evidence suggests that governance institutionalization, modular architecture, and community expansion function as mutually supportive factors, collectively shaping the project's recent development trajectory.

ACKNOWLEDGMENT

This work was supported by the National Key Research and Development Program of China (Project No. 2023YFB3309000). Qinyue Zhu is the corresponding author.

REFERENCES

1. X. Xia, S. Zhao, X. Zhang, Z. Lou, W. Wang, and F. Bi, "Understanding the archived projects on GitHub," in *Proc. IEEE Int. Conf. Softw. Anal., Evol. Reeng. (SANER)*, Piscataway, NJ, USA: IEEE Press, 2023, pp. 13–24, doi: 10.1109/SANER56733.2023.00012.
2. C. Alves, J. Oliveira, and S. Jansen, "Understanding governance mechanisms and health in software ecosystems: A systematic literature review," in *Proc. Int. Conf. Enterprise Inf. Syst.*, Cham, Switzerland: Springer-Verlag, 2018, pp. 517–542, doi: 10.1007/978-3-319-93375-7_24.

3. F. Han, S. Zhao, W. Wang, J. Peng, and X. Xia, "OpenRank: A centrality algorithm for high-dimensional heterogeneous networks in open source collaboration," *Inf. Sci.*, vol. 730, Mar. 2026, Art. no. 122893, doi: 10.1016/j.ins.2025.122893. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0020025525010291
4. Z. Shengyu et al., "OpenRank leaderboard: Motivating open source collaborations through social network evaluation in Alibaba," in *Proc. IEEE/ACM 46rd Int. Conf. Softw. Eng.: Softw. Eng. Pract. (ICSE-SEIP)*, Piscataway, NJ, USA: IEEE Press, 2024, pp. 346–357.
5. W. Huang et al., "OSGraph: A data visualization insight platform for open source community," in *Proc. 29th Int. Conf. Database Syst. Adv. Appl.*, Singapore: Springer-Verlag, 2024, pp. 476–479, doi: 10.1007/978-981-97-5575-2_42.

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Digital Object Identifier 10.1109/MC.2026.3672957