Human Activity Ecosystems in the Software Engineering

Nykolay Sydorov[1,*,†], Nika Sydorova[2,†] Olha Cholyshkina[3,†] and Pylyp Prystavka[4,†]

[1] National Technical University of Ukraine Igor Sikorsky Kyiv Polytechnic Institute, Prospect Beresteiskyi (former Peremohy) 37, 03056, Kyiv, Ukraine,
[2] "VTI"Private Joint Stock Company, F.Pushynoi str. 30/32, 03115 Kyiv, Ukraine,
[3] Taras Shevchenko National University of Kyiv, 60 Volodymyrska Street, 01033 Kyiv, Ukraine,
[4] The State University "Kyiv Aviation Institute", 1 Lubomyr Huzar Avenue, 03058 Kyiv, Ukraine

Abstract

The application of the ecosystem concept to a field that is fundamentally different from ecology necessitates the identification of appropriate analogies. This is particularly relevant in relation to landscapes, chains of energy and material exchange (such as trophic chains), and nutrient cycles. Without establishing such parallels within software engineering, ecosystem-related studies risk being reduced to traditional systems analysis, leaving the ecosystem notion as little more than an appealing metaphor. The purpose of this article is to draw the attention of the software engineering community to ecosystem research and to show that software engineering ecosystems exist. Based on the concept of ecosystem in biology and taking into account the concept of software ecosystem, the previously introduced concept of software engineering ecosystem is reviewed. According to the nature of the landscape, all software engineering ecosystems can be divided into two types - ecosystems of human activity landscapes and ecosystems of software landscapes. In this article ecosystems of human activity landscapes are examined. The anthropos as new biotic component and the anthropogenic artifacts as new abiotic components in the software engineering ecosystem are introduced. The ecosystems of human activity landscapes should be considered as a population of organisms and, therefore, as a system of the supra-organismal level. In the context of the software engineering habitats of anthropos their activity leads to processes that can be a linear (chains), nonlinear (networks), or repetitive (cycles). The following processes are looking: software engineering life cycle; cycles of data, information and knowledge; software reuse cycle (this cycle is analogous to nutritional cycles); value chain/web - an analogue of energy chain; waste cycles (Reuse, Rework, and Recovery). These processes must be objects for the ecosystems study. The literature review of the state of the ecosystem research for the ecosystems of human activity landscapes has been carried out.

Keywords

software engineering, software ecosystem, software engineering ecosystem, value chain

1. Introduction

Introducing the ecosystem concept into software engineering reveals challenges similar to those encountered in other non-biological disciplines — particularly concerning the definition of the term and its applicability in research [1]. Applying this concept in a domain so distinct from ecology, such as software engineering, requires researchers to establish relevant analogies. These include, most notably, the notions of landscape, chains of energy and matter flow (e.g., trophic chains), and nutrient cycles. Without such analogical foundations, ecosystem studies in software engineering risk being reduced to conventional systems analysis, rendering the ecosystem framework more of an appealing metaphor than a practical research tool.

Workshop "Software engineering and semantic technologies" SEST, co-located with 15th International Scientific and Practical Programming Conference UkrPROG'2025, May 13-14, 2025, Kyiv, Ukraine
* Corresponding author.
† These authors contributed equally.
Nyksydorov@gmail.com (N.Sydorov); nika.sidorova@gmail.com (N.Sydorova); Olha.cholyshkina@knu.ua (O. Cholyshkina); Chindakor37@gmail.com (P.Prystavka)
0000-0003-0800-1668 (N.Sydorov); 0000-0002-2989-3637 (N. Sydorova); 0000-0002-0681-0413 (O. Cholyshkina); 0000-0002-0360-2459 (P.Prystavka)

The study in [2] supports the relevance of employing the ecosystem concept in software engineering, provided that the analogy with ecosystem of ecology is preserved. This article aims to raise awareness within the software engineering community about the concept of the software engineering ecosystem and to look that the ecosystems of the human activity landscapes are exist. That by the review of the relevant literature is presented.

2. The Software engineering ecosystem

In [2], based on the hypothesis that software engineering — like ecology — encompasses a broader spectrum of ecosystems beyond the commonly referenced software ecosystems, the concept of software engineering ecosystems (SwEECO) was introduced, along with flows and chains analogous to those found in biological systems. Following the same perspective outlined in [2], this article adopts a similar conceptual approach.

The ecosystem is a conceptual framework rather than a tangible entity and as a rule, it constitutes a system. This framework can be applied to biogeocenoses situated within landscapes that represent the domain of software engineering. Any system located within a specific landscape – characterized by the presence of material and energy flows or their analogs, and comprising at least two living entities (organisms) – may be examined as a SwEECO. The boundaries of such a landscape are determined by the researcher in accordance with the goals of the study.

As an analogue of energy, the concept of value is used, based on the energy theory of value [3]. The structural approach is used to define ecosystems [4]. Therefore, in addition to the abiotic component and value, there are four types of ecosystem structure elements: activities; actors that carry out activities; positions that determine actors within the flow of activities; and connections that determine the transfer of value and artifacts between actors. Activities are at the center of ecosystem definition. An ecosystem is made sustainable by the interaction of actors in such a way that the value materializes. The chain of value creation by subjects through the use and creation of anthropomorphic abiotic components (artifacts) is used as an analogue of the trophic chain.

Artificial biota – computer programs – operate within software landscapes. There are landscapes where both types of biota (humans and computer programs) operate [5]. For a system formed by artificial biota (software ecosystem), the chain of formation of an emergent function is a value creation chain. Software engineering is considered as part of human activity aimed at transforming the biosphere into the anthroposphere (noosphere). Occupying a certain area of the biosphere, software engineering carries out activities aimed at solving practical problems arising in other territories (domains).

In general, the following types of the software engineering activity within human activity habitats can be distinguished [2]:

- Software engineering education and research. The habitat consists of universities and fundamental research organizations;
- Software engineering. The habitat is organizations that transform the results of the fundamental research to recommendations for practical application;
- Software development and maintenance. The habitat consists of organizations that create and maintain software products for different domains;
- Software market. The habitat includes organizations that supply software products;

- Software operation. The habitat is defined on other territories on that the software product is used;

- Executing software. The habitat is the software products themselves.

These activities are carried out in the context of the biosphere. Therefore, biogeochemical cycles and the wastes resulting from these activities should be studied in SwEECO [6]. Considering the territory of software engineering as part of a living system, in which a biogeocenosis occurs, both biotic and abiotic components, as well as biogeochemical cycles are of interest. New aspects of SwEECO research are related to the placement of their landscapes in the anthroposphere. Therefore, anthroposes are new biotic, and anthropogenic artifacts are new abiotic. Inherent only to software engineering ecosystems new networks and cycles are arise. That opens up new types of SwEECO research along with the known from ecology. Thus, in the anthroposphere, the object of ecosystem research in the territory of software engineering will be the human habitat and its social systems [2]. In the software ecosystem, software product as territory, data, information and knowledge as components of flows should be considered.

In the work [2], a classification of SwEECO was represented. According to the nature of the landscape, all ecosystems can be divided into two types - ecosystems of the human activity landscape (ecosystems of engineering included in the software engineering and non-engineering ecosystems) and ecosystems of software landscape. For example, as the second type, the programing style as the software artifact of the individual-based SwEECO or big data software ecosystem as the system of systems [7, 8].

In the context of the software engineering habitats of anthropos their activity to lead to processes that can be a linear (chains), nonlinear (networks) and repetitive (cycles). These processes must be objects for the ecosystems study regardless of SwEECO type.

In [6], drawing on studies of biological ecosystems, various types of research applying the ecosystem concept to software engineering were examined. These studies were categorized into two main groups: fundamental (basic) research and applied (target-oriented) research. The first group consists of naturalistic, long-term and ecosystem history studies. The second group consists of structural, functional and system analysis. It was shown, when studying SwEECO, traditional approaches to studying systems (structural, functional and system analysis) are used. However, the specific characteristics of ecosystem research must also be taken into account [6].

3. Literature Review

The goal of this review firstly, to define if there are already descriptions in the literature of ecosystems that are similar to SwEECO. Secondly, to find out the state of ecosystem research in context of SwEECO. For these goals are formulated the following two research questions:

(RQ1) What types of the ecosystems of human activity landscapes are represented in the literature today?

(RQ2) What ecosystem research has been conducted on the ecosystems of the human activity landscapes to date?

Below are the results of the analysis.

(RQ1) What types of s the ecosystems of the human activity landscapes are represented in the literature today?

We will analyze the literature in accordance with types of the ecosystems of the human activity landscapes.

3.1. Ecosystems of the software engineering education and research landscape

In the article [9], looked ecosystem of the 'knowledge triangle' (education, research and innovation) into a research university on the example of software engineering education. In the article [10], proposed the student-stakeholder-university ecosystem model for Software Engineering Education. In this paper presents a study of the lasting impact on both students and external stakeholders from a project-based software engineering course at Link¨ oping University, Sweden. This is done from the perspective of the relationship between the university, the students and the external stakeholders as a holistic ecosystem, with a goal of achieving sustainable results for all participants. The works [11, 12] are not directly related to SwEECO, but can be used as a basis for their initial study. Paper [13] proposes to divide the academic process into discrete components that have well-developed measures. This paper also proposes a reconfigured Porter's "value chain" model for the higher education value chain with its own value drivers and relationships. This has implications for software engineering value chain research in general and specifically in the context of education and research ecosystems [2].

3.2. Ecosystems of the software engineering research landscape

Article [14] offers both theoretical and practical insights into the core elements and driving factors that contribute to the development of a software startup ecosystem. It presents a generalized methodology and a conceptual framework, which can serve as a foundation for further research in the domain of Software Startup Ecosystems.

In article [15], a division of the knowledge ecosystem into two types was proposed: ecosystems of users and producers of knowledge. A distinction is drawn between knowledge ecosystems for creating a domain knowledge (it can be software engineering domain) and those searching knowledge within a domain knowledge for own research goals. In work it is characterized as prefigurative and partial forms of organizing. This perspective can be applied to software engineering research ecosystems.

3.3. Ecosystems of the software engineering development and maintenance landscape

In the work [16], describes creating the environment, tools, and activities of DevSecOps as an ecosystem. The four dimensions introduced: culture, automation and measures, processes and practices, and system and architecture are looked in article. From the perspective of SwEECO concept, culture plays an important role [2]. Initially, the space of future ecosystem is the landscape. Then, a biota is located on the landscape and the landscape can be considered as an ecotope. Before biota start create value it begins the activity of transforming the ecotope into a biotope. It is important to determine the nature, activities and results of the biota's activity in transforming an ecotope into a biotope. This can be done using of the software engineering culture [2]. In the work [17], a definition of software testing ecosystem (STECO) is proposed and how it can be used for tested to improve software quality. This work supports our view of studying individual phases of the software life cycle as ecosystems [2]. In work [18] propose a Software Ecosystem platform to support the development and management of Recommender Systems, allowing for integration between multiple applications and other Software Ecosystems. Thus, this ecosystem is proposed as a tool for use in software engineering. In [19], the i* modeling ecosystem framework is employed to support the sustainable development and evolution of a software development company. This framework facilitates the analysis of driving forces that lead to transitions between different organizational configurations.

3.4. Ecosystems of the software product market landscape

Software engineering market ecosystems are the closest to the concept of software ecosystems. In the work [20] indicates that software ecosystems, before taking their niche in the category of business ecosystems, have long been considered as a yet-another-instance of business ecosystems and studied in the same way. This view of software ecosystems can be found in the work [21]. However, it should be noted that the products of the software engineering market ecosystem can be not only software products, but also tools, assets and artifacts that are of interest to market stakeholders. The article [22], described the component-based software development ecosystem and its main service is the supply of components to the market.

3.5. Ecosystems of the software engineering product operation landscape

Ecosystems of operation of software engineering products will be created in those numerous domains where the products are operated. Of the few, one can cite works in which the domains of operation of scientific software are studied [23, 24].

(RQ2) What ecosystem study has been done for the ecosystems of the human activity landscapes today?

3.6. Naturalistic, Long-term studies

Paper [25] presents identifying software engineering assets and summarized in a taxonomy. Article [26] considers a subset of communities found on GitHub and identifies a variety of roles. Paper [27] presents the software value map as a first step towards a complete categorization of value aspects.

3.7. Value chain studies

The article [28] explores the concept of unified software value chain and represents a first empirical proof of concept.

3.8. Reuse cycle of the legacy software studies

The article [16] explores the concept of value networks within the context of DevSecOps. Although the work [26] does not directly address reuse cycles, it offers insights that may be applicable to their analysis.

For other types of ecosystem studies, please refer to work [6].

3.9. Reporting

We have summarized the results in the following tables.

Table 1

(RQ1) What types of the ecosystems of the human activity landscapes are represented in the literature today?

Type of SwEECO	Works
Ecosystems of the software engineering education and research landscape	[9 - 12]
Ecosystems of the software engineering research landscape	[13, 14]

Ecosystems of the software engineering development and maintenance landscape	[15 - 19]
Ecosystems of the software product market landscape	[19, 21]
Ecosystems of the software engineering product operation landscape	[22, 23]

Table 2

(RQ2) What ecosystem study has been done for the ecosystems of the human activity landscapes today?

Type of ecosystem study	Works
Naturalistic, Long-term studies	[25 - 27]
Value chain studies	[28]
Reuse cycle of the legacy software studies	[16, 26]

3.10. Threats to validity

To find answers to the questions posed (RQ1, RQ2), we used Google Scholar and search strings formulated to help answer these questions. This is due to the fact that searching for answers to these questions in both Google and Google Scholar resulted in an overly broad set of results. Therefore, for the search, firstly, we restricted our search to Google Scholar only, and secondly, we did not use search phrases in quotation marks — for example, “software engineering ecosystem” and “ecosystem research” — because Google Scholar does not return any results for such queries. We softened the requirements by deleting the phrases in quotation marks, but left the requirement that articles should contain terms from the designations of SwEECO and ecosystem study types (tab. 1, 2), and also, we searched only for full-text articles in English and did not limit the search by time period. We understand that the search results significantly depend on the terminology used by the authors of the articles we found. Therefore, we analyzed the full text of each found article and discussed the results. The results of the discussion were further reviewed by independent experts. We did not follow a formal review protocol, as our goal was not to conduct an exhaustive review. It was enough for us to find at least a few articles that confirmed the hypotheses presented in the questions (RQ1, RQ2). We came to the conclusion that there are studies related to some types of SwEECO and ecosystem research, as defined earlier.

4. Conclusion

This study builds upon the authors’ previous research and reflects their perspective on the integration of biological ecosystem concepts into software engineering. It emphasizes the limitations of current interpretations of the ecosystem metaphor within the software domain, particularly when contrasted with its use in biology. A key distinction arises from the prevailing treatment of software ecosystems as networks centered around a dominant entity - typically the core software product or platform. This interpretation, referred to as the "ecosystem-as-affiliation"

model in [6], lacks essential characteristics found in natural ecosystems, such as landscapes, boundaries, and cycles and chains. Consequently, the term "software ecosystem" often appears to be more of a trending label than a rigorously grounded concept. This article proposes a shift in perspective towards the "ecosystem-as-structure" model, wherein the ecosystem is viewed as a coordinated set of activities shaped by a specific value proposition [6]. We reviewed Human Activity Ecosystems in Software Engineering and performed a literature review to demonstrate the existence of research for such ecosystems. Future research will aim to conduct naturalistic studies of SwEECO and investigate how the ecosystem paradigm can be applied in practice.

Declaration on Generative AI

During the preparation of this work, the authors used X-GPT-4 in order to Grammar and spelling check.

References

[1] S. Hyrynsalmi, S. M. Hyrynsalmi, Ecosystem: A Zombie Category?, in: The Proceedings of IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC), Valbonne Sophia-Antipolis, France 17 – 19 June 2019, pp.759-767.

[2] N. Sydorov, Software Engineering Ecosystems, in: Proceedings of the 13th International Scientific and Practical Programming Conference UkrProg 2022, Kyiv, Ukraine, October 11-12, 2022, CEUR Workshop Proceedings, vol. Vol-3501, 2023.

[3] R. Costanza, C. J. Cleveland, Value theory and energy, in: Encyclopedia of energy, 6, (2004), pp. 337 - 346.

[4] R. Adner, Ecosystem as Structure: An Actionable Construct for Strategy, in: Journal of Management Vol. 43 No. 1, January (2017), pp. 39–58.

[5] D. Ackley, Real artificial life: Where we may be, in: The Proceedings of Artificial Life VII, Portland, Oregon, August 2000

[6] N. A. Sydorov, ECOSYSTEM research IN SOFTWARE ENGINEERING, http://doi.org/10.15407/pp2024.04.114.

[7] N. Sydorov, Programming Style as an Artefact of a Software Artefacts Ecosystem, in: Proceedings of Advances in Computer Science for Engineering and Education Applications, Springer, Cham, 2021, pp. 244-255.

[8] N. Sydorov, N. Sydorova, Software Engineering and Big Data Software, CEUR Workshop Proceedings, vol. Vol-3501, (CEUR-WS.org).

[9] R. Nikolov, S. Ilieva, Building a Research University Ecosystem: the Case of Software Engineering Education at Sofia University, in: ESEC/FSE'07, September 3-7, 2007, Cavtat near Dubrovnik, Croatia.

[10] Daniel Ståhl, Kristian Sandahl and Lena Buffoni, An Eco-System Approach to Project-Based Learning in Software Engineering Education, IEEE TRANSACTIONS ON EDUCATION, VOL. 65, NO. 4, November 2022.

[11] J. Reyna, Digital Teaching and Learning Ecosystem (DTLE): A Theoretical Approach for Online Learning Environments, in: ASCILITE Publications · December 2011, 1083-1087.

[12] E. Coutinho, C. I. M. Bezerra, I. Santos,A Software Ecosystem for a Virtual Learning Environment: SOLAR SECO, in: 2017 IEEE/ACM Joint 5th International Workshop on Software Engineering for Systems-of-Systems and 11th Workshop on Distributed Software Development, Software Ecosystems and Systems-of-Systems (JSOS), May 2017, DOI: 10.1109/JSOS.2017.

[13] V. Pathak, K. Pathak, Reconfiguring the higher education value chain, in: Management in Education, 24(4) 166–171.

[14] Fabio Kon, Daniel Cukier, Claudia Melo, Orit Hazzan and Harry Yuklea. A Conceptual Framework for Software Startup Ecosystems: the case of Israel. Technical Report RT-MAC-2015-01, June 2015.

[15] K. Järvi, A. Almpanopoulou, P. Ritala, Organization of knowledge ecosystems: Pregurative and partial forms, Research Policy, Volume 47, Issue 8, Oct. 2018, P. 1523-1537

[16] J. Morales, R. Turner, S. Miller, Guide to Implementing DevSecOps for a System of Systems in Highly Regulated Environments, TECHNICAL REPORT, CMU/SEI-2020-TR-002, April 2020.

[17] I. Santos, E. F. Coutinho, S. R. S. Souza, Software testing ecosystems insights and research opportunities, SBES'20, October 21–23, 2020, Natal, Brazil.

[18] A. Abdalla, V. Ströele, A Software Ecosystem platform for the development of Recommender Systems, DOI: https://doi.org/10.21203/rs.3.rs-34335/v1.

[19] M. H. Sadi, E. Yu, Analyzing the Evolution of Software Development: from Creative Chaos to Software Ecosystems, Conference: 2014 IEEE Eighth International Conference on Research Challenges in Information Science (RCIS), May 2014.

[20] S. Jansen and M.A. Cusumano. Defining software ecosystems: a survey of software platforms and business network governance. Software ecosystems: analyzing and managing business networks in the software industry, 13, 2013.

[21] E. Yu, S. Deng, Understanding Software Ecosystems: A Strategic Modeling Approach, in: Proceedings of the Workshop on Software Ecosystems 2011, 65 - 76.

[22] M. Usman, D, Badampudi, An Ecosystem for the Large-Scale Reuse of Microservices in a Cloud-Native Context, in: IEEE Software, Volume: 39, Issue 5, Sept.-Oct., 2022.

[23] C. Fan Du, J. Howison, An Ecosystem Perspective of Scientific Software Developer Productivity, White paper submission to Collegeville Workshop 2020.

[24] J. Howison., E. Deelman, M. J. McLennan, Understanding the scientific software ecosystem and its impact: Current and future measures, Research Evaluation, 24 (2015), pp. 454–470.

[25] E. Zabardast, J. Gonzalez-Huerta, T. Gorschek, (2023). A taxonomy of assets for the development of software-intensive products and services. Journal of Systems and Software, 202, Article 111701. https://doi.org/10.1016/j.jss.2023.111701.

[26] J. Arndt, J. Dibbern, The Tension between Integration and Fragmentation in a Component Based Software Development Ecosystem, in: Proceedings of the 39th Hawaii International Conference on System Sciences - 2006.

[27] M. Khurum, T. Gorschek, M. Wilson, The software value map— an exhaustive collection of value aspects for the development of software intensive products, J. Softw. Evol. and Proc. 2013; 25:711–741.

[28] A. Pussep, T. Widjaja, M. Schief, The Software Value Chain as an Analytical Framework for the Software Industry and Its Exemplary Application for Vertical Integration Measurement, in: Proceedings of the Seventeenth Americas Conference on Information Systems, Detroit, Michigan August 4th-7th 2011.