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Knowledge Ecosystem: A Sustainable Theoretical Approach

Ana Iolanda VODĂ[1], Sergiu BORTOŞ[2], Daniela Tatiana ŞOITU[3]

Abstract
A Knowledge Ecosystem (KE) refers to a system of interconnected components that work together to create, share, and use knowledge. It includes the processes, tools, and platforms that support the creation, dissemination, and application of knowledge. A knowledge ecosystem's main attribute is to generate new knowledge and valuable open-ended solutions for the participating actors that drive innovation, improve decision-making, and support learning and growth. This paper provides an overview of the knowledge ecosystem concept, which gain traction in recent research, with a focus on how the knowledge ecosystem is organised and the relationship between components. This paper contributes to research on knowledge ecosystems by describing not only knowledge ecosystem forms of organisation, but also the main methodological approaches used in the evaluation of the concept.

Keywords: Knowledge Ecosystem, Prefigurative Organisation, Partial Organisation, Methodological Approaches

1. Introduction

The Nobel Memorial Economic Prize winner in 2009, Elinor Ostrom, has stressed the impact of a better use of resources at the local level paves good communication for a sustainable approach to living. Starting from this frame, we may extend the algorithm to the knowledge ecosystem and its sustainable impact.
This work is performing the first needed steps, by reviewing and analysing the conceptual frames of a "knowledge ecosystem". Few papers have already analysed the processes associated with initiating, functioning (Sakar, 2013), developing, and extending the knowledge ecosystem. Knowledge is a valuable resource that is requesting a better share, use, and valorisation at the (extended) local level (Sudhakar, 2020). People, data, and networks are the three keys to a knowledge ecosystem. How diverse and vivid are human resources, the data, as knowledge and innovation, the digital or social networks, represent just a few of the possible links and paths of how an ecosystem performs.
The interest in knowledge ecosystems must be connected to the global concern for sustainability. The three bottom-up pillars of sustainability - considering people, planet, and profit, respective social, environmental, and economic dimensions – are followed, now, on the global level, by the targets of the 17 goals of "UN Agenda 2030" (UN, 2015). One way of reaching these is the European funding programs underlying transformative

[1]Department of Management, Marketing, and Business Administration, Faculty of Economics and Business Administration, Alexandru Ioan Cuza University of Iaşi, Romania
[2]Department of Social Sciences and Humanities, Institute of Interdisciplinary Research, Alexandru Ioan Cuza University of Iaşi, Romania.
[3]Department of Sociology and Social Work, Faculty of Philosophy and Social-Political Sciences, Alexandru Ioan Cuza University of Iaşi, Romania.

modules at the society level, from a sustainable approach. More concretely, the Horizon Europe Support Actions (SWAFS)[1] are encouraging the new European Alliances of Universities to invest in research and innovation by focusing on eight transformative modules; two of these are dedicated to strengthening the links of universities with local actors from the administrative, economy, with cities' citizens with the aim of framing and, where is the case, developing the local knowledge ecosystems. There are at least two European documents from September 2020 (the "Communication from European Commission on a new European Research Area for Research and Innovation"[2] and the Report "A robust innovation ecosystem for the future of Europe" from the European Innovation Council (EIC) Task Force, Unit of Innovation Ecosystems on the results of the stakeholder consultation[3]) are significant for our current work. The *Communication*, released on 30 September 2020, has framed 14 key actions to be developed by 2030, among which the one aiming to develop and test a networking framework in support of Europe's Research and Innovation ecosystems, building on existing capacities, to strengthen excellence and maximise the value of knowledge creation, circulation, and use".
The paper is organized as follows. Section 2. describes, in brief, the definitions and main characteristics of the ecosystems in general and knowledge ecosystems in particular. The next section presents the main forms of organizing the knowledge ecosystem and the relationship between subsystems. Section 4 describes the main methodologies used in analysing knowledge ecosystems from qualitative, quantitative, or mixed approaches. Section 5 describes the related approach to sustainability, and the last section concludes and suggests further approaches to the topic.

2. Ecosystems definition and types

Over the years, different types of ecosystems have been conceptualised, such as a) business ecosystem, b) innovation ecosystems, c) natural ecological ecosystems, d) digital ecosystems, and e) knowledge ecosystems (Peltoniemi and Vuori 2004; Isenberg, 2011; Moore, 1993). The knowledge of ecosystem dynamics and characteristics is drawn from innovation studies, entrepreneurship research, and strategy studies, which contribute to the conceptual distinction between different ecosystems. This expansion of ecosystem research has resulted in a wide range of definitions, which indicates key features, similarities, and differences between various ecosystem types.

a) *The business ecosystem* indicates companies' capabilities to co-evolve around innovation, support new product creation, satisfy client's needs, and embrace the next round of innovations. The system assumes joint actors' involvement in reaching common goals, with profits and benefits shared among them (Moore, 1993).

b) *The innovation ecosystem* focal point is the development of innovation attainable through collaboration between entities, which combine their individual offerings into a coherent, customer-facing solution (Adner, 2006).

[1] See more at: https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en

[2] See more at: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1749

[3] See more at: https://op.europa.eu/en/publication-detail/-/publication/c7552948-f6fc-11ea-991b-01aa75ed71a1

c) *Ecological ecosystem*. The concept of an ecosystem as a beneficial environment has been early acknowledged in the work of Becattini (1979). Starting with Moore (1993), the notion of the ecosystem and its ecological approach to strategy has been applied in numerous organisational contexts, gaining significant traction among strategy scholars and practitioners (Moore, 1993; Daymond et al., 2022). Ecosystems incorporate organizations' aspirations to co-evolve along the lines of shared visions (Järvi et al., 2018). From this perspective, knowledge encompasses how various actors shared wisdom, understanding, and learn among themselves, and at the same time, develop and accumulate new ideas.

d) *Digital ecosystem* represents a technical infrastructure that finds and connects services and information enabling network transactions, and digital object(s) distribution (Nachira et al. 2007).

e) In comparison with business ecosystems or innovation ecosystems, the concept of a *knowledge ecosystem* is relatively new (Jucevičius, 2022). The concept gained greater attention, especially in the context of the COVID-19 pandemic when businesses had to adapt to the crises, which determined an enhancement of the importance of knowledge sharing, development, and adaptation (Grumadaitė et al., 2022). In terms of Reischauer et al. (2021), the knowledge ecosystem has a particular feature in comparison with community characteristics for the innovation ecosystem, namely a more diverse sample of actors involved in such scientific activities. Yang et al. (2009) presented three common features of a knowledge ecosystem that are similar to a natural ecological system: the presence of individuals and groups of individuals; the adaptation characteristic to a knowledge ecosystem in continuous change and movement; and the creation of social networks of cooperation and competition. Although the concept of knowledge ecosystem has been built on the analogy with ecological systems and their process (Bratianu and Hadad, 2019), it refers to how different systems interact according to established principles and set of values, in order to facilitate knowledge production, transfer, and exploitation. The involved actors are interdependent and heterogeneous, seeking complementarities where possible and joining up to exploit opportunities (Bray, 2007; Bratianu and Hadad, 2019). It was documented before that the concept of a knowledge ecosystem is imported from the one of a digital ecosystem (Bray, 2007). The reason for such an approach is linked with the theory according to which a proper infrastructure within an organic self-organized structure or environment that favours innovation, (self)learning, and human interaction are needed, being opposed to the mainstream top-down education system (Deparis et al., 2014). The static knowledge from knowledge management systems seems obsolete and needs to be reformed through a much more focus on dynamic knowledge (Scarlat et al. 2011).

2.1 Knowledge ecosystem definitions and characteristics

Figure 1. shows the number of studies on the knowledge ecosystem by year, from 2000 to 2022. The figure shows references to the knowledge ecosystem that grew over the last 17 years and across a range of domains.

This tendency implies that the knowledge ecosystem concept was increasingly used in the field of Management (35 publications), Information Science (19 publications), Business (18 publications); and Computer Science (Computer Science Theory methods (11

publications) and Computer Science Information Systems (10 publications)), among others (**Figure 2**.)

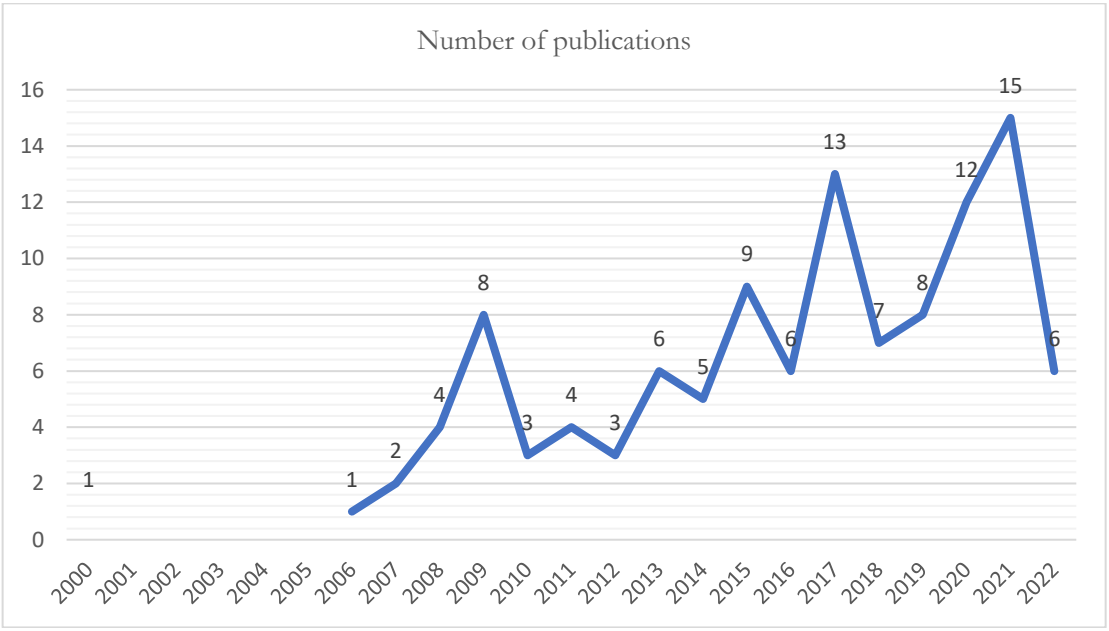

Figure 1. Number of papers published per year (Web of Science Core Collection, 2000-2022)

Figure 2. Knowledge ecosystem publication distribution by fields (Web of Science Core Collection, 2000–2022)

A description in brief of the most common definitions is presented in **Table 1**. In a knowledge ecosystem, public research organisations and universities are their main actors, and their main objective is to co-create, explore, and share knowledge using knowledge hubs as the main infrastructure and, at the same time, being dependent on value chains where the value creation is produced by these actors from top to bottom (Aksenova et al., 2019). Oliver et al. (2020) add other actors involved in knowledge ecosystems besides public research organisations, such as universities and public research institutes, namely large organisations, all these institutions being extremely densely clustered from a geographical point of view. The universities and research institutes are the most visible building block in a knowledge ecosystem among other actors (Bahrami and Evans, 2014).

Table 1. Knowledge ecosystem definitions

Definitions	Author (year)
"May form around specific technological or societal challenges"	Dougherty and Dunne (2011); Clarysse et al. (2014)
"Geographically co-located organizations that activate in complementary fields"	Van der Borgh et al. (2012)
"The concept addresses a set of basic or applied science problems, leading over time to knowledge exploitation and actor-specific appropriation"	Franzoni and Sauermann (2014); Perkmann and Schildt (2015).
"Central actors involved in knowledge ecosystem are local universities and public research organizations"	Clarysse et al. (2014)
" Knowledge exploration is implemented through collaborative research work"	Valkokari (2015)
"Involved actors bound together by a joint search for valuable knowledge" and "in pursuit of the higher-order	Järvi et al. (2018)

goals unattainable independently"	
Participating actors are "not equally active all the time or simultaneously" Their organization is "fluid and as an ongoing process"	Davis and Eisenhardt (2011); Davis (2016) Dobusch and Schoeneborn (2015); Barry and Rerup (2006).
"Problems are ill-defined, preferences are fluid, and solutions emerge in action" "Can be understood as meta-organizations"	Garud et al. (2008) Ahrne and Brunsson (2005); Gulati et al. (2012).
Shows how different systems interact according to established principles and sets of values, in order to facilitate knowledge production, transfer, and exploitation	Bratianu and Hadad (2019)
The focus of a knowledge ecosystem is „on the creation of new knowledge".	Carrozza et al., (2020)

Source: authors' representation

As seen in **Table 1**. the authors define a knowledge ecosystem as "knowledge intensive companies and other participants that depend on each other in terms of effectiveness and efficiency and need to be geographically co-located entities in complementary fields" (Van der Borgh et al., 2012). The focus of a knowledge ecosystem is on the creation of new knowledge (Carrozza et al., 2020), through the interaction between local know-how and innovation, new markets, and economies (Fasoli and Tassinari, 2017). However, given the capacity of modern technologies, co-location proximity may not always be considered a determining factor (Still et al., 2014). Coughlan (2014) suggests that co-location can also mean virtual proximity between actors developed using ITC technologies. Moreover, the mix of virtual and physical proximity can increase an organization's innovation capacity (Coughlan, 2014). Similarly, Ghazinoory et al. (2021) found that, on one hand, there is a positive relationship between innovation and the presence of knowledge ecosystems and business ecosystems. On the other hand, the innovation sphere (ecotone) represents the interface between these two ecosystems.

Other authors define a knowledge ecosystem by focusing on how the knowledge develops, transfers, interacts and integrates (Carayannis and Campbell, 2009; Cobben et al., 2022). For instance, Scarlat et al. (2011, 32) defined a knowledge ecosystem as "knowledge-based systems consisting of networks of interconnected people, knowledge and technical means by which knowledge is created, organised, selected, summarised and shared with all other entities/systems in the environment that require knowledge." Its emergence could be the solution to solve the unproductive confusion between knowledge as a process versus an object (Scarlat et al., 2011). Such ecosystems may evolve to address specific basic and applied science problems, which may lead over time to knowledge exploitation and actor-specific appropriation (Franzoni and Sauermann, 2014). The entire process is characterised by a deliberate search for valuable knowledge (Järvi et al., 2018). Bi et al. (2009) highlighted the main three roles' people play in a knowledge ecosystem from knowledge producer to knowledge consumer and the knowledge decomposer.

The knowledge ecosystem can be considered a meta-organization (Gulati et al., 2012) in the sense that autonomous actors are bound together by their desire to search for and generate new knowledge (Jarvi et al., 2018). The concept of organizationally translates to

the actors' ability to be organized collectively although they remain autonomous organizations (Jarvi et al., 2018). This implies that the ecosystem may be formed around specific technological or societal challenges (Dougherty and Dunne, 2011). By integrating participants' complementarities in value creation, the ecosystem may determine a more effective knowledge search, in comparison to any individual actor alone (Järvi et al., 2018). A knowledge ecosystem should have a minimum size, otherwise, it could be inappropriate and inoperative if the relationships are too exclusive, rigid, and autarchic (Bathelt and Glückler, 2011). But Granovetter (1973) argued the benefits of "the strength of weak ties" to create new knowledge and innovation. The explanation lies in a theory that certifies that social networks built on strong ties are more likely to protect and secure the status quo, therefore being less disposed to import disruptive forms of knowledge (Bathelt and Cohendet, 2014).

Kreiger (2016) put great emphasis on the idea that a knowledge ecosystem is a complex balanced system that uses and produces knowledge for a certain purpose, its components being people and their interactions with the mission to foster growth in an area of concern and to improve decision-making and innovation using advanced evolutionary networks of collaboration. In other words, Kreiger (2016: 3) defines a knowledge ecosystem as "a complex, self-organizing system of people interacting with each other and their knowledge and technical environments for growing collective intelligence and capabilities."

In the knowledge ecosystem local universities and public research organizations are usually considered central actors, which are responsible for generating knowledge at the stage of "pre-commercial engagement" (Clarysse et al., 2014). In knowledge ecosystems, diverse actors participate in a process that takes the shape of vertical and horizontal networks targeted at creating novel solutions and valuable propositions which generate new knowledge (Jarvi et al., 2018). The process of exploration is reached only through collaborative research work, which is seen as a central piece in the knowledge ecosystem (Rådberg and Löfsten, 2022). In the knowledge ecosystem, the creation of knowledge depends on the active participation of multiple actors, while knowledge search can be contingent upon how an actor's participation is organised (Felin and Zenger, 2014). However, for-profit actors may also benefit from knowledge exploration, and by engaging in a joint search they may achieve higher-order goals, unattainable in an independent quest (Van der Borgh et al., 2012). However, the degree of involvement in knowledge creation it's not clearly defined. For instance, the participants can be completely open (Franzoni, Sauermann, 2014), clearly bounded (van der Borgh et al., 2012), equally active (Davis and Eisenhardts, 2011), or simultaneously active (Davis, 2016). In the knowledge ecosystem, the involved actors possess a certain degree of autonomy and adaptation capacity. This implies that the knowledge network is constantly evolving, and sometimes the boundaries between the knowledge ecosystem and its environment are no longer clearly visible.

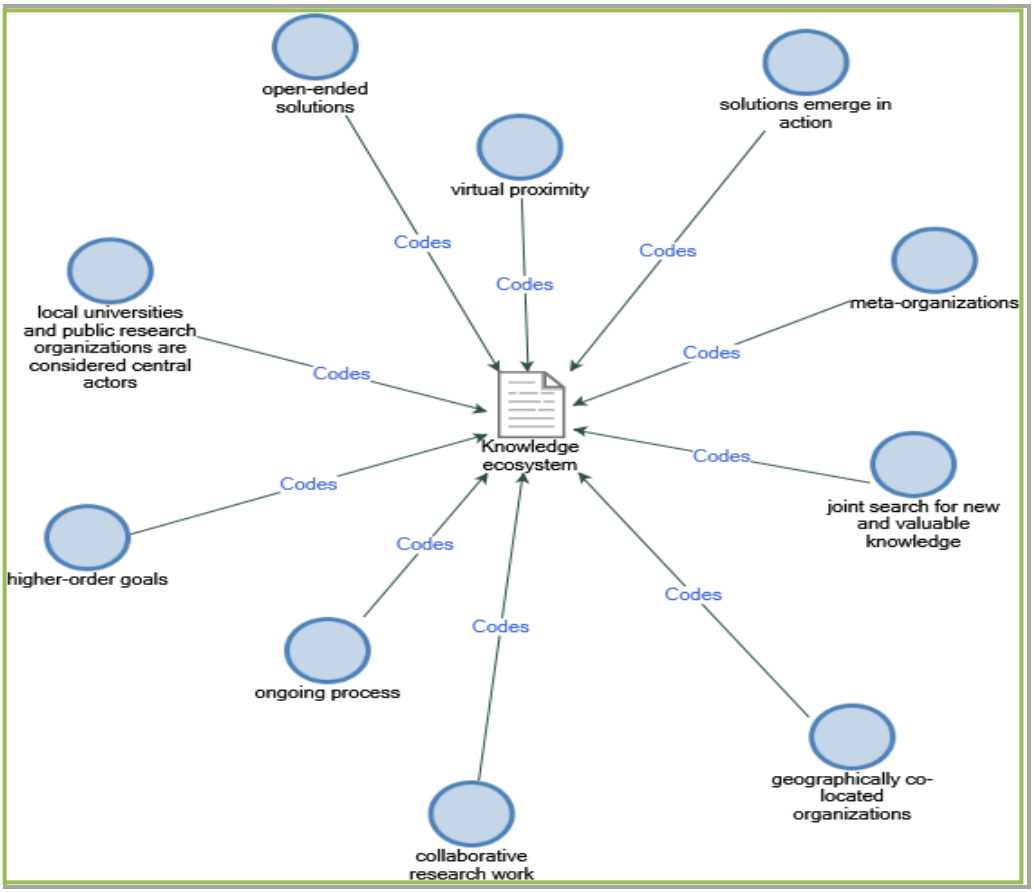

Figure 3. Main attributes of the knowledge ecosystem
Source: author's representation Nvivo 12 Pro.

Other authors consider the knowledge ecosystem as being a versatile and inclusive system, promoting open-ended solutions (Almpanopoulou, 2019). The networking system has the capacity to adapt, being defined by the knowledge flows and intensive interaction of different actors that possess a notable degree of autonomy and self-organization (Jucevičius, 2022).

Jarvi et al. (2018) differentiate between two types of knowledge in the ecosystem: a) the search for new knowledge, a collectively orientated process; b) exploiting and developing the existing knowledge, activities that imply a monitoring act by formal members/entities. Such ecosystems integrate users and producers of knowledge, which develops and evolve around a joint knowledge search (Järvi, et al., 2018). Based on that, knowledge ecosystem interactions, symbiosis, resource orchestration, and value co-creation are encouraged, a process that leads to transforming involved entities from knowledge users to knowledge sharers and knowledge creators (Lindtner, 2014). The entire knowledge process requires both dispersion of knowledge and other resources but also the coordination of knowledge creation across different entities and domains to achieve the established goal.

Figure 3. shows the main characteristics of the knowledge ecosystem that have been developed in the specialised literature. A knowledge ecosystem can be seen as a virtual and/or physical meta-organization that functions as a spiral connecting quintuple helixes, a collaborative system that facilitates knowledge production, transfer, and exploitation, in reaching established common goals. The joint search of the involved actors can be seen as a response to finding new solutions to complex problems, unattainable to individual actors alone.

3. Forms of organizing in the knowledge ecosystem

Jarvi et al. (2018) propose two forms of organizing in the knowledge ecosystem: prefigurative and partial organisation. The suggested types differ from each other in terms of: i) knowledge domain searching; ii) implications of the joint knowledge search on organizing; iii) involved challenges; iv) degree of organizability; v) basis of participation; and vi) forms of coordination (See Table 2.)

- *Prefigurative organisation of knowledge ecosystem*. The initial step of the process is finding the knowledge domain and formulating the common goal. After that, through dialog and discussions, the members establish how that common goal can be reached. However, the common goal must simultaneously fulfill two objectives: *first*, to be partially aligned with the funding partners' private interests, and *second*, to be unique and distinctive.

Given the high complexity of the process, the participants must reveal to some extent their interests and intentions, and those pieces of information must be put together. Another distinctive feature of the prefigurative organisation is that the members are self-resources and unobligated: i) any forms of compensation are postponed until the developed program secures national or international funding; ii) also, participants have no obligation related to the preparation of the proposal and can redraw at any point. This approach allows the existence of different group configurations in terms of size or composition (see **Table 2**.) Lastly, is an informal organizational structure, without written guidelines for operating, and where the relations between involved actors are created naturally (Jarvi et al., 2018).

- *Partial organization of knowledge ecosystem*. In comparison with prefigurative organization, the search process is organized within the knowledge domain and the common goal is shared by all the ecosystem actors. It allows some degree of flexibility since the knowledge domain can be reconfigured based on the new knowledge developed by updating and broadening the common goal. The actor's particular knowledge is revealed selectively by two means: sharing his own goals on a yearly basis or presenting intermediate outputs. Another feature is that the basis of participation is membership affiliated, and the process is characterized by formal procedures based on imposed rules and regulations. Lastly, the financial resources are collectively shared by the actors and their contribution is monitored (Jarvi et al., 2018).

Table 2. Forms of organizing in the knowledge ecosystem

Main attributes	The criteria for differentiation	
	Prefigurative	**Partial**
Knowledge Domain Searching	• initial screening for the field of action (or problem range) • the knowledge domain is disclosed by exploring its provisional scope • formulating/defining the common goal • the common goal is unique and distinctive	• all involved actors share the knowledge domain • the knowledge domain is reconstructed, reassessed, and updated by rethinking the common goal • selectively revealing the actor's particular knowledge (e.g., yearly basis or intermediate outputs)
Implications of the Joint Knowledge Search on Organizing	• in this form, the ecosystem does not possess a distinctive identity. • preliminary bases are set once the actors' goal is established.	• the main criteria of organisationally: collective actor-hood. • the knowledge ecosystem has a distinguished character, in comparison to other systems
Involved Challenges	• the knowledge search is characterized by ambiguity and the absence of a straightforward objective.	• finding a path by prioritizing the members' common goals over their own goals
Degree of Organizability	• elements of organizing are initially neglected	• elements of organizational structures are in place and in use
Basis of Participation	• unobligated participation • possibility to drop out at any level of involvement • self-resourced participation	• membership-based participation; • formal membership based on regulations. • collective allocation of financial resources to members to support their participation
Forms of Coordination	• informal coordination • absence of formal rules or any determined structures • high degree of complexity	• formal regulation and monitoring

Source: Adapted after Jarvi et al., (2018)

Other scholars highlighted the need for a common shared knowledge stock for generating a knowledge ecosystem among the "extended peer community" to integrate both the "scientific and extra-scientific expertise from the relevant stakeholder communities and linking scientific problems with societal problems." (Popa et al., 2015: 6) Mason et al. (2021: 412) provided arguments that "The extended peer community approach is an attempt to implement post-normal science principles, which emphasize the benefits of knowledge held by non-scientists to the scientific process itself." **Figure 4**. presents the collective interaction and exchange of knowledge between five subsystems: education, economic subsystem, political subsystem, civil society, and natural environment. The

system's role is to create synergies between the economy, democracy, and society and at the same time take into consideration the societal exchange, transfer of knowledge, and the natural environment (Shi and Chen, 2022).

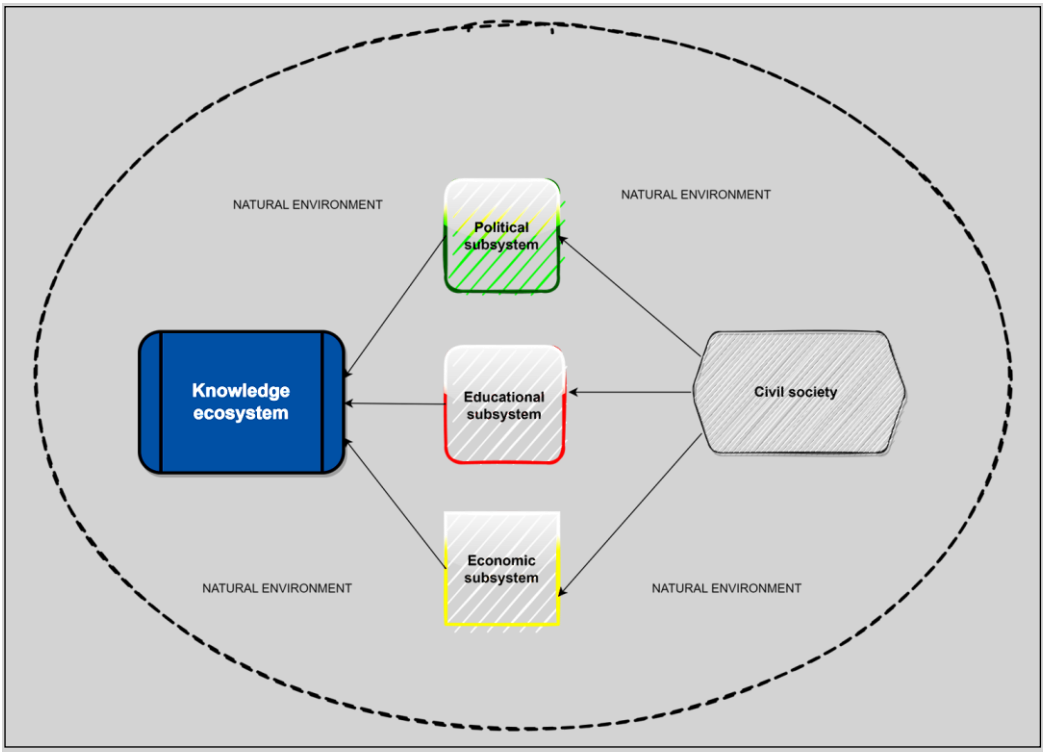

Figure 4. KE subsystems
Source: Shi & Chen (2022), p. 6

Clarysse et al. (2014) emphasized several advantages provided by knowledge ecosystems. One advantage is given by the mobility of personnel and the flow of tacit knowledge. The second one is based on reduced costs associated with this kind of technological cluster. A third one has links with the external economies of scale that allow firms to capture benefits from collective resources. A fourth is given by an increased speed of innovation diffusion and local firms' innovative products and services. A fifth is related to belonging to a global research network which, further, could compensate for the impossibility to join a technological hub in geographical proximity, therefore without sacrificing innovative productivity. The last one makes a clear association between a high density of knowledge ecosystems and the high production of innovative output.

4. A short analysis of methodological approaches used in knowledge ecosystem research

Table 3 presents some examples of methodological approaches that can be used in knowledge ecosystem research (Cronin et al., 2008). Most studies used either quantitative or qualitative methodologies. For instance, the study developed by Entezari (2019) analyses the knowledge ecosystem, using a mixed methodology, a quantitative method complemented by a theoretical analysis of the concept, aggregating data from 140 countries based on the World Bank dataset.

Table 3: Methodological approaches used in knowledge ecosystem research

Title	Author and year	Journal (full reference)	Purpose of study	Type of study	Setting	Data collection method	Major findings	Recommendations/ Limits
"Modelling the national knowledge ecosystem: Policy implications for Iran"	Entezari, Y. (2019).	*Procedia Computer Science*, 158, 826-835.	- to analyze the structure of the national knowledge ecosystem, using both theoretical and empirical analysis	mixed	140 countries, worldwide, observation unit – country, focus on Iran	n/a, data from World Bank, Global Competitiveness Index, Global Innovation Index, Global Entrepreneurship Index, Economic Freedom Index	- key actors of the knowledge ecosystem are: universities; public research institutes; knowledge government agencies; state laboratories; innovative entrepreneurs and knowledge-based enterprises; capitalist ventures; civil society and media. - the author describes the processes developed by the interaction (internal or external) between these stakeholders, which can be treated as an ecosystem; - the knowledge ecosystem relations can take the following forms: producing, distributing, attracting, and commercializing.	n/a
"Building social media-based knowledge ecosystems for enhancing business resilience through mass collaboration"	Yu, J., Pauleen, D.J., Taskin, N. and Jafarzadeh, H. (2022).	*International Journal of Organizational Analysis*, 30(5), 1063-1084	- to analyze how mass collaboration through social media-based knowledge ecosystems (mainly knowledge creation and innovation) can enhance the resilience of Small and Medium-Sized enterprises (SMSEs)	qualitative	n/a	text analytics tool	- mass collaboration can be used as a tool to develop new business ideas and enhance the knowledge of the SMSEs' ecosystems, to increase resilience to unexpected events such as COVID-19.	- conceptual model and cannot be generalized
"Competition or collaboration? –	Aaldering, L. J., Leker, J., Hoon Song, C. (2019).	*Journal of Cleaner Production*,	- the study analyzed electric mobility	quantitative	United States	n/a (collection of patent data	- the research demonstrated the connections between the	- the forecasting model can be improved using other additional

Analysis of technological knowledge ecosystem within the field of alternative powertrain systems: A patent-based approach"		212, 362-371	using a knowledge ecosystem perspective to understand the cohesiveness of them			and patent citation)	discoveries of different alternative systems, using the concepts of knowledge and knowledge ecosystems; - the findings showed that beyond competition between new discoveries, innovation must be driven to the same goal, using an ecosystem approach.	techniques (such as machine learning)
"Creating value in ecosystems: Crossing the chasm between knowledge and business ecosystems"	Clarysse, B., Wright, M., Bruneel, J., Mahajan, A. (2014).	*Research Policy*, 43(7), 2014, 1164-1176.	- to analyze a knowledge ecosystem and how this can be translated into a business ecosystem to improve the existing policies	quantitative	Flanders, Belgium (138 innovative start-ups in the region)	unique hand-collected database	- the knowledge ecosystem is developed around central actors and is well structured at the local level, however the business ecosystem is almost non-existent at the local level; - value creation processes determine the main difference between these ecosystems.	- the main recommendation is to extend the analysis to other regions and to compare them, to see if there are any processes of knowledge co-evolving in the two ecosystems; - it can be used as a mix of short-term and long-term measures applied for start-ups, to understand the impact of these on the ecosystems.
"Organization of knowledge ecosystems: Prefigurative and partial forms"	Järvi, K., Almpanopoulou, A., & Ritala, P. (2018).	*Research Policy*, *47*(8), 1523-1537	- to describe the organization of the knowledge ecosystems, using a perspective that implies knowledge producers and knowledge users.	qualitative	Finnish SHOK research programs	semi-structured interviews & document analysis	- the knowledge ecosystem can be differentiated between those who are looking for a field/domain and the other ones that searching within a domain; - the organization of the knowledge ecosystems is structured around two different processes: participation and collaboration.	- the results of the study can be used to scale up the study.
"Designing informal learning experiences for early career academics using a knowledge ecosystem model"	Miller, F., Partridge, H., Bruce, C., & Hemmings, B. (2016).	Journal of Further and Higher Education, 41(5), 692–705.	- to present how early career academics can use the knowledge ecosystem model to develop their social networks	qualitative	n/a	interviews	- the informal sphere of the knowledge ecosystem is important in providing learning experiences and designing interactions between involved actors.	n/a
"From Finnish AEC knowledge ecosystem to business ecosystem: lessons learned from the national deployment of BIM"	Aksenova, G., Kiviniemi, A., Kocaturk, T., & Lejeune, A. (2018).	*Construction Management and Economics*, 1–19.	- to capture, identify and characterize the relationships between actors in knowledge ecosystem	qualitative (grounded theory & document analysis)	Finland	interviews	- The Finnish national programs developed knowledge and innovation ecosystems that should evolve into business ecosystems; - the strategies used in value creation processes are particular for	- future research can explore other characteristics of the actors from the business ecosystem and how relationships between these actors can produce knowledge that individual actors cannot provide without interactions.

			s and innovation ecosystems.				business ecosystems and knowledge/innovation ecosystems and can affect the systemic evolution of each type of ecosystem and the relationships between them.	
"Knowledge transfer in university quadruple helix ecosystems: an absorptive capacity perspective"	Miller, K., McAdam, R., Moffett, S., Alexander, A. and Puthusserry, P. (2016)	*R&D Management*, 46: 383-399.	- to understand how knowledge transfer can be used in open innovation, based on the quadruple helix stakeholder's classification and the interactions between them	qualitative	n/a	semi-structured interviews, observational analysis & document analysis	- the results showed that the universities should improve their mechanisms to collaborate with the other stakeholders from the quadruple helix, and they should play a central role in coordinating the knowledge transfer processes in the open innovation ecosystems.	- future research can focus on the intermediaries, mechanisms, and platforms that are used by the stakeholders engaged in the quadruple helix and knowledge transfer.

Source: Author's representation.

The main findings of this study highlight that the key actors involved in the knowledge ecosystem are: universities, public research institutes, knowledge government agencies, state laboratories, innovative entrepreneurs and knowledge-based enterprises, capitalist ventures, civil society, and media. Entezari (2019) describes the processes developed by the interaction (internal or external) between the stakeholders, which can be treated as an ecosystem. The role of the relations developed in these ecosystems is to accumulate knowledge and to use it in different forms such as: producing, distributing, attracting, and commercializing.

Yu et al. (2022) used a qualitative methodology, based on a text analytics tool, to analyse how mass collaboration through social media-based knowledge ecosystems (mainly knowledge creation and innovation processes) can enhance the resilience of small and medium-sized enterprises. The findings of the study underline that mass collaboration can be used as a tool to develop new business ideas and to respond quickly and adaptively to crises (e.g., financial crises or sanitary crises).

Aaldering et al. (2019) developed a quantitative methodology to analyse patent data and patent citation of electric mobility using a knowledge ecosystem approach to understand their cohesiveness of them. The findings showed that beyond competition between new discoveries, innovation must be driven to the same goal, using an ecosystem approach. Clarysse et al. (2014) analysed quantitatively 138 innovative start-ups from Flanders, Belgium, and how this can be translated into better policies for the business ecosystem. The findings of the study showed that the knowledge ecosystem is developed and well-structured at the analysed local level. However, the business ecosystem is almost non-existent, and these two types of ecosystems need to be treated differently, given the differences in the value creation processes used in them. Järvi et al. (2018) used a qualitative methodology to describe the organization of the knowledge ecosystem from Finland, based on the perspective that implies knowledge producers and knowledge users. The

main findings of the study showed that an ecosystem can be differentiated between those who are looking for a field/domain and the other ones that searching within a domain and that the organization is structured around two different processes: participation and collaboration.
Miller, Partridge et al. (2016) used a qualitative methodology to present how early career academics can use the knowledge ecosystem model to develop their social networks. The study's findings showed the importance of the informal sphere of the knowledge ecosystem in providing learning experiences and designing interactions between the involved actors (see Table 3).
Aksenova et al. (2018) developed a qualitative methodology, using grounded theory and document analysis to capture, identify and characterize the relationships between actors in knowledge ecosystems and innovation ecosystems from Finland. The results of the study pointed out that the Finnish national programs developed knowledge and innovation ecosystems that should evolve in business ecosystems and that different strategies are used in value-creation processes for business ecosystems and knowledge or innovation ecosystems, which can affect the systemic evolution of each type of ecosystems and the relationships between them. Miller, McAdam et al. (2016) developed a qualitative methodology to understand how knowledge transfer can be used in open innovation, based on the quadruple helix stakeholder's classification and the interactions between them. The results showed that knowledge transfer contributed to the progress of the stakeholders and in knowledge acquisition, transformation, and exploitation. The results showed that the universities should improve their mechanisms to collaborate with other stakeholders from the quadruple helix, and they should play a central role in coordinating the knowledge transfer processes in the open innovation ecosystems.

5. Towards a sustainable knowledge ecosystem

The sustainability paradigm has emerged as a key framework for addressing the complex and interconnected challenges facing humanity, including a wide range of issues such as economic, climate change, biodiversity, and social issues (Edwards, 2005; De Vries, 2012; Burns, 2012). On the other hand, the knowledge ecosystem refers to the interdependent relationships established between individuals, organisations, institutions, and stakeholders that produce, disseminate and use knowledge, pursuing their own objectives but simultaneously systemic outcomes (Clarysse et al., 2014, Valkokari, 2015; Perkmann and Schildt, 2015; Järvi et al., 2018).
The relationship between the knowledge ecosystem and the sustainability paradigm can be considered significant, as both focus on how interdependent relationships develop between different stakeholders, entities, organisations, and other types of actors. For example, a knowledge ecosystem can be seen as a component of the wider socio-ecological system, which includes the social, economic, and environmental domains, and any of these can be considered dimensions of sustainability (Lehtonen, 2014). In this context, the sustainability approach can be understood as a broader framework that provides an understanding of the interactions between the different components of a knowledge ecosystem and their impact on sustainability outcomes.

Another way in which the linking of the knowledge ecosystem with the sustainability paradigm can be leveraged is through a focus on collaboration and knowledge co-creation. By bringing together these perspectives and the expertise already accumulated in the two areas, knowledge ecosystems can facilitate the development of more holistic and integrated solutions to sustainability challenges (Clark et al., 2016). In doing so, we can see local knowledge brought together with scientific and technological knowledge, as well as the involvement of decision-makers in adopting sustainable measures tailored to ecosystem needs, resulting in sustainable knowledge (Murdoch, 1994). Thus, linking the knowledge ecosystem with the sustainability paradigm is a meaningful one, as it starts from the assumption that both have in common the development of interdependent relationships between different entities. By focusing on collaboration and co-creation of knowledge, knowledge ecosystems can contribute to the development and achievement of appropriate responses to sustainability challenges, resulting in a sustainable knowledge ecosystem (Wilson, 2021).

Conclusions

Different scholars have conceptualised various types of ecosystems: a) business ecosystem, b) innovation ecosystems, c) natural ecological ecosystems, d) digital ecosystems, and e) knowledge ecosystems (Peltoniemi and Vuori 2004; Isenberg, 2011; Moore, 1993). Our focus was on briefly introducing these ecosystem types, with a special emphasis on knowledge ecosystem definitions, characteristics, and proliferation. Our research showed that the references to the knowledge ecosystem have grown over the last 17 years and across a range of domains: management, information science, business, and computer science among others (Web of Science, 2000-2022). Research to date has covered the knowledge ecosystem's main attributes which have been acknowledged by many scholars. We contribute to the literature by describing six main attributes used in analysing the knowledge ecosystem, namely: a) this type of ecosystem implies collaborative research work, and local universities and public research institutes are considered central actors (Clarysse et al. 2014); b) it's an ongoing process that it's constantly evolving to provide open-ended solutions, and new knowledge (Dobusch and Schoeneborn, 2015; c) its main purpose is to achieve higher-order goals unattainable by individuals along but through joint search and collaboration (Järvi et al. 2018); d) knowledge ecosystems can be seen as meta-organisations focused on knowledge enhances activities usually developed by actors located in closed proximity (Ahrne and Brunsson, 2005); Gulati et al. 2012); Van der Borgh et al. 2012); The focus of a knowledge ecosystem is „on the creation of new knowledge"; e) the main focus is „on the creation of new knowledge" (Carrozza et al., 2020), and on how knowledge is developed, developed, transferred, and integrated among involved systems and subsystems; f) this complex ecosystem formed usually around technological or societal challenges encourages value co-creation of new knowledge among actors, which accommodates a transformative process from users to knowledge sharers and then, knowledge creators; and g) lastly, the organisation of knowledge ecosystems differs on two dimensions: prefigurative and partial organisation. These two vary in terms of the knowledge domain, implication, involved challenges, degree of organizability, participation base scenario, and coordination (Jarvi et al., 2018).

We also contribute to the literature by presenting the main methodological approaches (quantitative, qualitative, and mixed methods), used in knowledge ecosystem assessment, which have been conducted in accordance with the complexity of the phenomenon, the analysed components, or relations. Lastly, the paper emphasises the importance of the relationship between the knowledge ecosystem and the sustainability paradigm which can be considered significant, as both focus on how interdependent relationships develop between different stakeholders, entities, organisations, and other types of actors (Lehtonen, 2014; Clark et al., 2016).

Like any research, this study has some limitations. We took into consideration only a limited number of definitions that have emerged from the literature, therefore future research could systematically review how multiple agents collaborate with each other, and the nature of the participation in the creation and search for new knowledge. A second limitation regards, the lack of empirical data that might have provided a better understanding of the concept and the involved relations between actors. Therefore, further research may enrich the present framework by investigating how activities are coordinated and how they support knowledge creation and search.

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