

Digital Ecosystems

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ABSTRACT

Digital ecosystems refer to dynamic, interconnected networks of organizations, individuals, technologies, and data that co-evolve through digital platforms and shared infrastructures. Enabled by advances in cloud computing, big data, artificial intelligence, and application programming interfaces (APIs), digital ecosystems facilitate collaboration, innovation, and value co-creation across traditional organizational boundaries. Unlike linear value chains, digital ecosystems are characterized by modular architectures, decentralized governance, and network effects, allowing diverse actors such as platform owners, complementors, and users to interact and adapt continuously. These ecosystems enhance scalability and flexibility but also introduce challenges related to governance, data ownership, security, and power asymmetries. In this paper, we highlight the core characteristics of digital ecosystems, their strategic importance, and the key managerial and regulatory implications associated with their development and sustainability in the digital economy.

KEYWORDS: *Digital ecosystems, digital platforms, shared infrastructures, cloud computing, big data, artificial intelligence, application programming interfaces (APIs), power asymmetries, data ownership, security, scalability, flexibility.*

INTRODUCTION

A digital ecosystem is a distributed, adaptive, open socio-technical system with properties of self-organization, scalability and sustainability inspired from natural ecosystems. It consists of interacting digital entities – such as organizations, people, software services data, platforms, and devices – that co-evolve, collaborate, and compete within a shared digital environment. Digital ecosystem models are informed by knowledge of natural ecosystems, especially for aspects related to competition and collaboration among diverse entities [1-5]. The term is used in the computer industry [6], the entertainment industry [7], and the World Economic Forum [8]. Modern theory of open and digital ecosystems represents dynamic, interconnected networks in which diverse participants, ranging from companies and institutions to startups and end-users, collaborate through digital platforms to co-create value across traditional organizational and industry boundaries [9], as shown in Figures 1 and 2.

An open and digital ecosystem is a dynamic, platform-based network in which organizations and users collaborate across industry boundaries through the exchange of data, finance, and product information enabled by application programming interfaces (APIs) [5] – which is built on the principles of Open Innovation and Open Data, as shown in Figure 3. Fasnacht emphasized on the convergence of commerce, social media, and finance – the so-called “golden Triangle of Ecosystems” – as a central characteristics of such ecosystems, enabling integrated offerings such as digital platforms and super-apps [9].

HISTORICAL BACKGROUND

Early 2000s – The European Commission’s ISTAG (Information Society Technologies Advisory Group) coined the term “digital ecosystem” to describe a self-organizing digital infrastructure.

It was in 2002 that the concept of Digital Business Ecosystems (DBEs) was put forward by a group of

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European researchers and practitioners, including Francesco Nachira, Paolo Dini, and Andrea Nicolai, who applied the general notion of digital ecosystems to model the process of adoption and development of ICT-based products and services in competitive, highly fragmented markets like the European one [10, 11]. Elizabeth Chang, Ernesto Damiani, and Tharam Dillion started in 2007 the IEEE Digital EcoSystems and Technologies Conference (IEEE DEST). Richard Chbeir, Youakim Badr, Dominique Laurent, and Hiroshi Ishikawa started in 2009 the ACM Conference on Management of Digital EcoSystems (MEDES) [5, 12].

2005 – Social media platforms like Facebook (2004) and YouTube (2005) emerged, creating new digital ecosystems, as shown in Figure 4.

2007 – Apple’s iPhone and App Store revolutionized mobile ecosystems.

2005-2010: This period saw the rise of social media and mobile platforms, expanding digital ecosystems.

2010s: Cloud computing (AWS, 2006), IoT, and AI transformed digital ecosystems [5, 13, 14], as shown in Figures 5-8.

KEY CHARACTERISTICS

Some of the key characteristics of digital ecosystems include:

1. Self-organization: Digital ecosystems are adequate and can reorganize themselves in response to changes.
2. Scalability: They can grow or shrink as needed, accommodating new users, services, or technologies.
3. Sustainability: Digital ecosystems aim to be resilient and maintain their functionality over time.
4. Dynamism: They are constantly evolving, with new technologies and innovations emerging.

Components:

- Physical Layer: These are the hardware devices like smartphones, laptops, and IoT devices.
- Information Layer: This is the data analytics tools, digital identity systems, and automation tools.
- Application Layer: Software applications, social media networks, and collaboration tools [15, 16].

TYPES OF DIGITAL ECOSYSTEMS

The types of digital ecosystems include:

- Platform Ecosystems: Multiple companies work together on a central platform, creating high-level collaboration. They are centralized platforms connecting users, developers, and partners (e.g., Apple App Store, Shopify Salesforce).

- Super Platform Ecosystems: Complex networks integrating multiple platforms and services into a single, comprehensive experience or integrated services capturing user data and offering adjacent business models (e.g., Amazon, WeChat, Apple).
- Functional Digital Ecosystems: Focus on specific functions or industries. It is formed around a specific product, service, or activity (e.g., photo editing suite).
- Digitizer Ecosystems: Focus is on updating traditional products with digital capabilities, often with lower management complexity (e.g., IoT in manufacturing) [17-19].

BENEFITS

Some of its benefits include:

- Enhanced User Experience: It ensures seamless interactions across devices and services.
- Innovations: Encourages experimentation and co-creation.
- Efficiency: Seamless processes and improves productivity.
- Faster technology adoption
- Creating new revenue streams
- Cost reduction through efficient business processes [17-19].

CHALLENGES FACED BY DIGITAL ECOSYSTEMS AND THE SOLUTIONS

As digital ecosystems (networks of platforms, users, organizations, data, and technologies that co-evolve) create huge value, they also come with some stubborn challenges. Stated below are the major challenges and practical solutions to them [20-22]:

1. Data Privacy and Security challenges: Digital ecosystems rely on large-scale data sharing across multiple actors, leading to increases in:
 - Risk of data breaches
 - Unauthorized data use
 - Loss of user trust
 - Regulatory non-compliance (e.g., GDPR)

Solutions:

- Privacy-by-design and security-by-design architectures
- Strong encryption and identity management
- Clear data governance and access controls
- Compliance with global data protection standards.

2. Lack of Interoperability and Standards

The challenge is that ecosystem participants often use incompatible systems, leading to [23, 24]:

- Data silos
- Integration complexity
- Reduced innovation and scalability

Solutions:

- Adoption of open standards and APIs

- Modular and platform-based architectures
- Industry-wide standard-setting initiatives

3. Governance and Power Imbalance

The challenge would involve dominant platform owners that may [25, 26]:

- Control access to data and users
- Extract disproportionate value
- Limit ecosystem partners' autonomy

Solutions:

- Transparent governance frameworks
- Fair value-sharing and participation rules
- Regulatory oversight and antitrust measures

4. Trust and Transparency

The challenge is that participants may lack trust due to [27, 28]:

- Opaque algorithms
- Unclear data usage
- Limited accountability mechanisms.

The solutions would include:

- Explainable AI and algorithmic transparency
- Clear ecosystem rules and dispute mechanisms
- Third-party audits and certifications

5. Cybersecurity Threats

The challenge is that highly connected ecosystems expand the attack surface, thereby increasing exposure to [29, 30]:

- Malware
- Ransomware
- Supply-chain attacks

Solutions:

- Continuous monitoring and threat intelligence sharing
- Zero-trust security models
- Ecosystem-wide cybersecurity standards

6. Digital Divide and Inclusion

Challenge: The challenge is the unequal access to digital infrastructure and skills, which can lead to [31, 32]:

- Excluding smaller firms and developing regions
- Reduce ecosystem diversity and resilience

Solutions will include:

- Investment in digital infrastructure
- Digital skills development programs
- Inclusive ecosystem design policies

7. Ecosystem Complexity and Coordination

The challenge to this is that as the ecosystems grow, they become harder to manage due to [33-35]:

- Multiple stakeholders with conflicting goals
- Rapid technological change
- Unclear roles and responsibilities

The solutions would include:

- Clear role definitions and value propositions
- Ecosystem orchestration capabilities
- Adaptive and agile governance models

FEASIBLE WAYS TO MOVE DIGITAL ECOSYSTEMS FORWARD

The feasible pathways to digital ecosystems is the need for combine platform coordination, open interoperability, trusted data governance, fair value sharing, decentralized architectures, and supportive regulation – to be treated as a socio-technical system, not just a technology stack. These will take the form of:

1. Platform-based orchestration (but with limits): This will be a shift from platform dominance to platform stewardship (with clear rules, transparent governance) [36, 37].
2. Interoperability through open standards and APIs: This will combine open standards with selective control over sensitive components [34, 38].
3. Data governance and trust infrastructures: Federated data models (data stays local but is usable) globally; and ensuring data trust and data spaces [39, 40].
4. Decentralized and distributed ecosystem models:- Ensure hybrid models: centralized coordination + decentralized execution [41, 42].
5. Ecosystem-level governance and shared value creation: Need to ensure (i) Multi-stakeholder governance bodies, and (ii) Transparent rule-setting and dispute mechanisms [23, 43].
6. Capability building and ecosystem literacy: This is via (i) Ecosystem maturity models, and (ii) Joint learning initiatives and sandboxes [44, 45].
7. Policy and regulation alignment: This must follow (i) Principle-based regulation, (ii) Regulatory sandboxes, and (iii) International coordination [46, 47].

CONCLUSION

Digital ecosystems mark a shift from firm-centric digitalization to network-based value creation, where organizations, technologies, data, and users jointly evolve. Their success depends not only on advanced technology but also on effective interoperability, governance, trust, and fair value-sharing mechanisms. While digital ecosystems enable innovation, scalability, and resilience, they also pose challenges related to power imbalances, data ownership, and regulatory complexity. Addressing these challenges requires ecosystem-level governance, open standards, and supportive policy frameworks. Ultimately, digital

ecosystem should be understood as socio-technical systems, whose long-term sustainability relies on aligning technological capabilities with collaborative organizational practices and inclusive governance structures. More information on Digital Ecosystems can be obtained in the books in [48-55] and the following related journals:

Journal of Strategic Information Systems
International Journal of e-Collaboration
Journal of Business Research
International Journal on Semantic Web and Information Systems
Journal of Management Information Systems (JMIS)
Technological Forecasting and Social Change
Information & Management
MIS Quarterly (MISQ)

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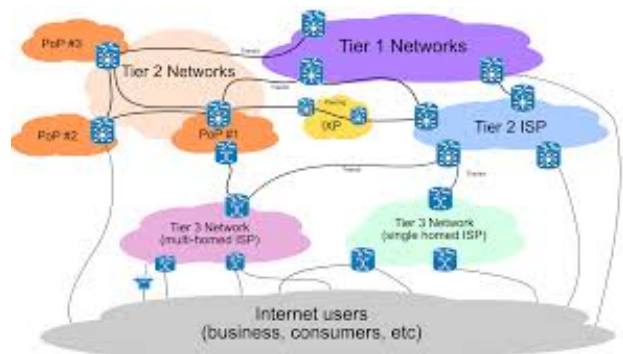


Figure 1. Tier 1 network
Source:

https://en.wikipedia.org/wiki/Tier_1_network



Figure 2. Startup ecosystem
Source:

https://en.wikipedia.org/wiki/Startup_ecosystem

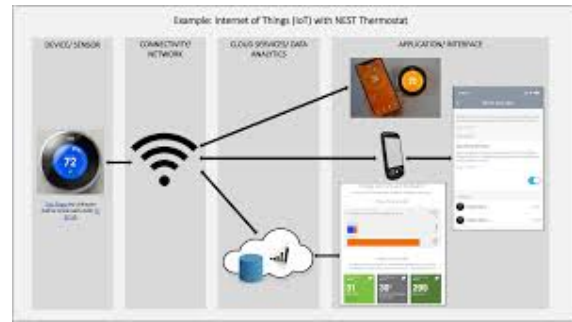


Figure 5. Internet of Things
Source:

https://en.wikipedia.org/wiki/Internet_of_things

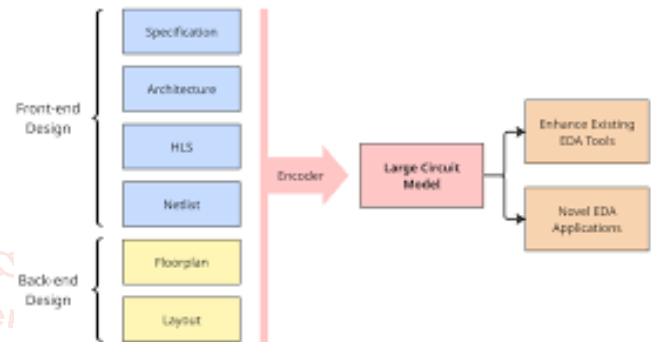


Figure 6. AI-driven design automation
Source: https://en.wikipedia.org/wiki/AI-driven_design_automation



Figure 3. Platform economy
Source:

https://en.wikipedia.org/wiki/Platform_economy

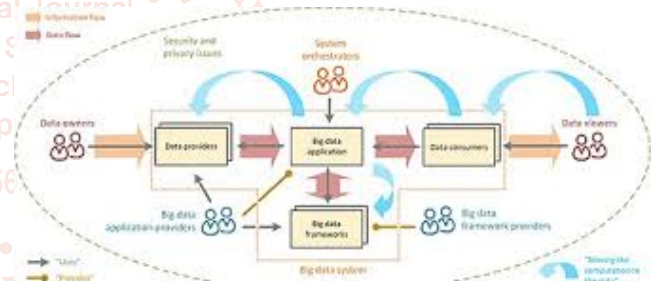


Figure 7. Big data
Source: https://en.wikipedia.org/wiki/Big_data



Figure 4. Social media

Source: https://en.wikipedia.org/wiki/Social_media

System (Perform Tasks)	Context (Frames the System)	
Reception/operation	Systems of Thought	Modes of thinking, philosophies, theories, ideologies
Interface	Forms of Knowledge	Research texts, manuals, magazines, websites, experience
Code (Software)	Finance	Business models, investment, grants, profit
Database	Political Economies	Policy, tax regimes, incentives, public/political opinion
Code(Operating System)	Governmentalities	Data standards, file formats, protocols, regulations, laws
	Infrastructures	Paper/pens, computers, sensors, servers, buildings
Material Platform (Hardware)	Practices	Techniques, learned behaviours, scientific conventions
	Organizations	Corporations, government agencies, NGOs, universities
	Subjectivities	Of data producers, curators, managers, analysts, users
	Places	Labs, offices, field sites, data centres, business parks
	Marketplace	For data, their derivatives, analysts, analytic software

Figure 8. Data ecosystem
Source:

https://en.wikipedia.org/wiki/Data_ecosystem