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BUILDING A TECHNOLOGICAL ECOSYSTEM IN THE CONTEXT OF DIGITAL TRANSFORMATION

Purpose. To substantiate scientific, methodological and practical developments aimed at transforming the national technological ecosystem and providing recommendations for the implementation of an adaptive digital business model focused on the effective integration of enterprises into technological ecosystems.

Methodology. The study uses general scientific methods: comparison, analogy, analysis and synthesis, system analysis, multi-criteria evaluation and matrix modeling methods. We use holistic, network, and cluster approaches to obtain the results of the research.

Findings. The article identifies the priorities for the transformation of the national technological ecosystem and offers recommendations for accelerating its development towards the formation of sustainable networks of interconnected enterprises based on advanced digital manufacturing technologies. The authors propose a new understanding of the "technological ecosystem" category's essence. We identify the key features and components of the technological ecosystem. The paper substantiates the principles of adapting digital business models to the technological profiles of both enterprises and the ecosystems into which they integrate. In accordance with the level of technological maturity and digital capabilities of enterprises and ecosystems, we offer digital frameworks adapted to changes in the technological space. We analyzed models and trajectories of integration taking into account the digital context and developed a toolkit for the effective functioning of an enterprise in a technological ecosystem. The study outlines the prospects for promoting the management practices of technological ecosystems by developing an integrated model that balances environmental, economic, and social sustainability. The model highlights the importance of digital and technological maturity, collaboration, and innovation as drivers of ecosystem adaptability and resilience.

Originality. We developed an adaptive digital business model focused on the effective integration of enterprises into technological ecosystems in the face of technological gaps and imbalances in industry potentials. The paper proposes a matrix of management projects, which, based on the assessment of technological (including digital) levels, determines the positions of enterprises and integration models that provide enterprises with flexibility in the context of digital transformation. The implementation of the integrated model contributes to the development of the ecosystem's technological potential, intensification of regional innovations, and achievement of a synergistic effect on a national scale.

Practical value. The recommendations can be used by technology companies, eco-industrial parks' management, and industrial symbiosis facilitators to develop program, project, and other long-term documents that formalize the business model, strategy, and policy for building the national technology ecosystem.

Keywords: *technological ecosystem, digital business model, innovation, logistics, communications, education, management, technological maturity*

Introduction. The prerequisites for the transition of the Ukrainian economy to the latest technological basis are a shift in emphasis towards a new center of economic growth and geopolitical influence, as well as the urgent need to ensure technological independence. The situational nature of the processes, as opposed to the evolutionary path of economic development, accelerates the processes of economic technologization, the processes of solving scientific problems, the transformation of the relevant management mechanisms and tools. The priority of technological development in the national security system and related processes is becoming evident, as confirmed by the focus on creating technological conditions for socio-economic progress. Many traditional scientific approaches to the study of socio-economic systems are used in isolation from each other, making it impossible to take into account the complexity of systemic formations and interactions in the modern economy. Holistic, network, cluster, and other approaches to economic development can be applied in a single complex within the framework of the ecosystem approach methodology. It distinguishes innovative, entrepreneurial, industrial, digital (platform) ecosystems, urban service ecosystems, and others, and considers the possibility of further integration of ecosystems on the scale of the regional economy. The unifying factor of economic ecosystems is the ability to self-organize, self-develop, self-regulate, and have a high level of adaptation. Despite the inherent horizontal interactions of economic ecosystems that exist outside a single center, artificially constructed ecosystems based on horizontal and vertical connections and hierarchical structures are not rejected. The latter are suggested to include the technological ecosystem based on advanced digital manufacturing technologies.

As globalization and accelerated digital transformation intensify in Ukraine, the technology ecosystem can play a key role in supporting businesses and regions, enabling them to form a sustainable basis for implementing advanced technologies, ensuring a continuous massive flow of innovations, and attracting investment. Thus, enterprises are challenged not only to adapt to changes but also to integrate into the technological ecosystem, which will support their technological development and provide access to advanced solutions and strategic resources. In this sense, enterprises at different levels of technological maturity face integration barriers and need to transform their business models to successfully adapt. A technology- and industry-specific integration concept allows for consideration of both internal and external technological constraints and the use of adequate cooperation methods to develop more effective integration strategies.

Literature review. Given the current trend of combining different products into a single comprehensive value proposition, from the functionality of a single product to products integrated into an extensive network of additional features, the ecosystem approach is coming to the fore. In this context, as noted by the authors [1], additional value (Surplus Value) for users of ecosystem products can be provided through an expanded package, accompanying services, and exclusive access to products of other ecosystem participants. Thus, according to researchers [2], the ecosystem approach allows attracting new participants to the established business model, which makes it possible to provide the market with the necessary innovative component based on the principle of emergence without radically abandoning the company's usual product.

Paper [3] emphasizes the fact that an ecosystem unites different actors who use innovative synergy in a single innovation space to achieve a common goal of generating value. There is also a dominant thesis that by creating an ecosystem, enterprises increase their own innovation and production and technological potential, since the innovation process involves the resources of various participants [4]. At the same time, the importance of technological and digital gaps in innovation chains is emphasized. Studying the evolution of industry, the authors [5] confirmed that the transition to industrial technological ecosystems is driven not only by economic benefits but also by the need for enterprises to meet strict requirements for environmental friendliness and safety.

Within the ecosystem, modern scholars [6] consider the competitive advantage of open value creation and the influential role of business model design focused on novelty and efficiency as a unique logic for directing interaction for the sake of accessing and using external resources. At the same time, experts [7] recognize the key role of digital technologies in building and developing ecosystem business models. A number of works [8–9] are dominated by the position that an ecosystem built on a digital platform contributes to a better understanding of customer needs, as well as the ability to develop special offers for different customer segments. Experts [10] provide evidence of the importance of platform ecosystems for the digital transformation of high-tech companies, providing access to resources and enabling joint ownership of assets. Research [11] focuses on methods of systematic assessment of stakeholder needs in the process of creating a smart/intelligent service ecosystem (SISE) for complex production environments. More services provided are able to be based on contextual data and big data that are accumulated and processed by the ecosystem using modern technologies.

Technological ecosystems play a key role in Industry 5.0's desire to go beyond traditional technical processes [12]. In this sense, the form of implementation of this strategy is a multifaceted platform ecosystem, which is a point of contact for numerous stakeholders [13]. Here, the key success factors are the introduction of technological diversity, the development of knowledge sharing mechanisms, the use of open innovation strategies, and overcoming resistance to change [14]. The authors of the study [15] emphasize that enterprises that are part of technological ecosystems are more diverse and adaptable.

Analyzing the work [16], it is possible to outline the prospects and priorities of domestic market structural transformations. In particular, the innovative infrastructure of industrial enterprises requires the use of modern technologies, systems and methods aimed at increasing efficiency, safety, environmental sustainability and competitiveness. In this aspect, researchers [17] proposed a methodological approach to assessing the effectiveness of innovative technology park projects, taking into account the specifics of Ukrainian legislation. According to the authors of [18], the development of advanced digital manufacturing technologies, infrastructure, and competencies is a key point of digital transformation. In this context, researchers [19] study models of digital transformation in which an enterprise becomes a local leader in a limited ecosystem, improving its own technological level through strategic technology implementation.

At the same time [20] focuses on the costs of digital entrepreneurship. The authors investigate the conflict of roles, enterprise productivity in ecosystems based on digital platforms, using factor analysis to test internal consistency and discriminant validity. A noteworthy study is [21], where the authors focus on the adaptation of business models to digital conditions. In particular, the authors consider the development of a framework, the content of digital business models and their features: the modern business model transformation is based on the megatrend of digitalization, which requires a balance between digital and physical assets. In this context, researchers [22] emphasize that the digital business model is the basic logic of a company that describes what benefits are provided to customers and partners through the use of digital data.

We agree with the study [23] that transition economies are characterized by weaker technological ecosystems compared to Western ones, significant dependence of enterprises on internal R&D, ability to learn new and modernize technologies, and international cooperation. In the authors' view, empirical research on the relationship between innovative business models and innovation efficiency needs to be intensified.

Considering the interest of the academic community in the problems of the formation of technological ecosystems, which is an objective phenomenon caused by fundamental changes, it is worth recognizing the insufficient research on the practical implementation of digital business models, the identification of key factors that determine the complex interactions that form these models.

Purpose. The purpose of the study is to substantiate scientific, methodological and practical developments aimed at transforming the national technological ecosystem and to provide recommendations for the implementation of an adaptive digital business model focused on the effective integration of enterprises into technological ecosystems in the context of digital transformation.

Methodology. The research methodology is based on the synthesis of economic and technological development and innovation theories. The research methods include general scientific methods of comparisons, analogies, analysis and synthesis, system analysis, methods of multi-criteria evaluation and matrix modeling. Holistic, network and cluster approaches are used in the research process.

Results. We define the technological ecosystem as a symbiosis of economic, scientific and educational entities that unite on a network basis to produce, promote and sell innovative products and services that can change existing markets or create new ones using a common set of technologies, knowledge or skills, jointly and competitively. This definition emphasizes the targeted nature of the technological ecosystem: ensuring technological achievements and innovation-driven economic growth.

The compliance of the technological ecosystem with the characteristics of artificial ecosystems leads to the definition of the system-forming element as a certain center around which the entire ecosystem will be formed. This center is the institutional system of technological development management.

The aggregate of certain properties of technological development and typical structures of known ecosystems make it possible to determine the structural components of the technological ecosystem. First of all, the composition of the technological ecosystem components is determined by the functional model of technological development management. The management system should ensure the integration of management of two meta-processes – research as well as production and technological activities with the dominance of the technological component based on ensuring the scientific component's role. One of the ways to overcome the shortcomings of innovation ecosystems in terms of innovations commercialization is to develop small innovative enterprises, whose work is to use (implement) the results of intellectual activity in practice. Another distinctive feature of a technological ecosystem is the breadth and orderliness of the actors system in the scientific and research sphere, which includes an innovative scientific and technological center, institutes of innovative development, an advanced engineering school, competence centers, and technology transfer centers. Special participants on the part of economic agents are also envisaged – a leading company, a technology company, and a small technology company. In addition, the mechanisms and tools used are involved and receive an impetus for development.

The technological ecosystem is equally represented by components of new products, technologies, and processes (high-tech products, critical technologies, end-to-end technologies, best available technology, localization of production, in-house technology development line, startup (technological); taxonomy of technological sovereignty projects). At the same time, venture capital investments and technological innovations are developing.

In a broad sense, a technological ecosystem can include: an institutional management system; a system of scientific and development institutions; a system of economic agents; a system of legal regulation and methodological support; a system of principles; a system of goals (and indicators), objectives, and mechanisms for technological development; a system of activities, programs, and projects; a system of interaction tools. The structure of the technological ecosystem corresponds to the characteristics of a network complex of interacting and interconnected components. At the same time, the state component of the ecosystem does not violate the logic of the ecosystem approach, but rather accelerates the processes of integration and mutually beneficial cooperation, ensuring the synergistic effect of the balanced functioning of the technological development ecosystem.

The transition of the innovation ecosystem to the technology ecosystem in Ukraine is consistent and objective. This is due to a change in the concept: the priority of research-based technology development is being replaced by the priority of its implementation and improvement in real production processes. The reason for this is that in the country's innovation ecosystem, the processes of science development as a sphere of new scientific knowledge circulation in the form of R&D results and production as a sphere of technology creation and renewal are separate and abstracted from each other. This point leads to technological "gaps" in production chains.

Let us consider the key differences between the technological ecosystem and the innovation ecosystem, which are as follows.

Priority of scientific thought development in the technological innovations direction. In a technological ecosystem, they are not an "additional" or "unintended" result of scientific research, but the main goal. This difference stems from the transition from the innovation development paradigm to the technological development paradigm based on technological sovereignty. The technological sovereignty establishment in our country depends on a number of factors that influence scientific and technological (S&T) progress and economic development. Some of them are: financing of science and technology; development of the scientific and technical base; human resources; infrastructure; regulatory environment; international cooperation. The development of technological sovereignty requires a comprehensive approach and consideration of all the above factors. The goal of such an approach is to create our own critical and cross-cutting technologies "under national control". This means that the direction of scientific research should be determined by the state, taking into account the priorities of technological development.

Relative autonomy of technology, S&T and industrial policies. This difference means that priorities for technological development should not be determined in the field of S&T, where the results of scientific research lead to technical innovation, which can only lead to the emergence of new technologies. And not in the field of industrial production, where the profitability of companies depends on the quantity and quality of the technologies used, regardless of where these technologies are produced (for example, abroad), but such interdependence does not guarantee the technological development of the national economy. Therefore, the technological progress of Ukraine's economy based on national technological priorities should be a separate area of state regulation and should give impetus to scientific, technical and industrial development.

Qualitatively new participants in the technology ecosystem are: technology holdings, research consortia, small technology companies, and professional technology intermediaries. This difference is reflected in the change of goals and formats, and the scale of interaction between ecosystem participants. Consequently, new types of organizations should emerge in the technological ecosystem in the research and education sector, the production sector, and in the field of technological intermediation. At the same time, these types of organizations should initially (at the stage of their formation) be distinguished by multi-functionality (for example, conducting research; launching startups and receiving a finished high-tech product), large-scale (using cooperative ties between the participants of associations and attracting external financing for high-tech projects), high sensitivity to market needs and adaptation to them (small forms of business organization), network format of interaction (which can be built by a participant in a network of Network connections between the elements of the technological ecosystem are transformed into processes of mutually beneficial exchange of research results and technologies; commercialization of ideas and technological startups.

New institutional framework, new forms and tools for technological development. The fourth difference is determined by the need for a new institutional superstructure that will provide more extensive and voluminous support from the state. At the same time, the role of state regulation should increase in terms of funding and change qualitatively towards greater transparency and stability.

The modern technology ecosystem consists of several key components that interact and create shared value:

- digital platforms that are the foundation for organizing the value creation process, ensuring interaction between participants;
- technological and cooperative chains that determine the sequence of actions and the relationship between participants in the production and supply of goods and services;
- key participants, which include: owners of digital platforms, associations (technology holdings, etc.), including educational, research, design and production facilities, pilot production; research and education structures (research consortia); small technology firms focused on both integration into production and technology chains of large businesses and independent deployment of mass production; professional technology intermediaries (brokers) that ensure the development of engineering services, technology and intellectual property transfer, and international cooperation;
- digitized business processes to increase the efficiency and transparency of interaction between participants;
- eco-resource potential that provides material resources for production and interaction between them;
- socio-cultural component, which includes organizational culture, social incentives, and a successful history of ecosystem development. The concept of a technology ecosystem offers several advantages for the participants and various types of interaction between companies: mining, manufacturing, processing, distributors, and retailers. First, these actors have diverse resources, and interaction allows them to share and exploit them together, which increases overall efficiency. Secondly, cooperation in ecosystems facilitates the exchange of technologies and best practices between participants, accelerating innovation processes. Thirdly, ecosystem participants combine competencies to solve common problems. Fourthly, joint participation in projects and developments allows for the distribution of risks and costs among ecosystem participants. Finally, effective cooperation with ecosystem partners helps participants gain access to new markets.

The instruments of the technological ecosystem should include industrial megaprojects, agreements between powerful technology companies and the government, and large-scale research initiatives in the priority areas of technological independence. It should be emphasized that these tools are aimed at creating a favorable environment that will ensure the "cultivation" of technologies in the national ecosystem of technological development.

The emergence of a technological ecosystem is accompanied by the formation of institutional conditions that also ensure the ecosystem's functioning at the regional level. In most regions, innovation clusters, industrial parks, small and medium-sized innovative enterprises, research and production holdings, and research and education consortia have been operating relatively steadily and for a long time, and engineering personnel are being trained. It is important to understand that in order to achieve the stated goals of the technological ecosystem, it is necessary to change the essence of these forms. An analysis of successful practices in the formation of a technological ecosystem has shown that the main ecosystem elements have already been formed and are functioning in the regions.

Ukraine is building best practices for the functioning of the innovation ecosystem, which ensures its transformation into a technological ecosystem. At the same time, the technological infrastructure has been developed, which consists of scientific and technological parts many institutions, and the processes of digital transformation accelerate the formation of the technological ecosystem. Some of the technological ecosystem elements in the regions include: innovation and industrial parks and technology parks (eco-parks), including the Institute of Electric Welding, the Institute of Single Crystals, and Vuhlemash; the Institute of Technical Thermophysics, Ukrinfotech, Semiconductors; Intelligent Information Technologies, etc. Among educational organizations, as an element of the technological ecosystem with its characteristic features (scale, multi-component, multi-functionality), we can single out Kyiv Polytechnic, which has a developed infrastructure for the creation and development of end-to-end technologies, trains and retrains personnel in this area, and facilitates the implementation of student technological startups. There are 16 officially registered technology parks in Ukraine. In continuation of this topic, we note that in early 2025, an updated version of the standard "Eco-industrial parks. Sustainability Criteria and Assessment Methods". The event was held in a hybrid format within the framework of the Global Eco-Industrial Parks Program in Ukraine (GEIPP), with the support of UNIDO and funding from Switzerland through the Swiss State Secretariat for Economic Affairs (SECO).

The years 2022/23 were extremely difficult for the whole country. Startups were no exception. However, despite all the conditions, many Ukrainian founders ma naged to consistently attract fresh investment. The mid-stage is usually the period when startups need large investments, in particular, thanks to a Series-A financing round. These investments help companies increase production, expand market geography, and implement strategic initiatives. An example of a successful Ukrainian startup is Carmoola, an Anglo-Ukrainian Fintech startup that raised $125 million in Series-A funding. Late-stage B/C startups, as potentially important market players that contribute to economic growth, also need permanent financial support. Late-stage startups bring innovations, create new jobs, and accelerate technological progress. In particular, the Ukrainian EdTech company Preply has raised $70 million in equity and loans. This funding will allow it to increase its Series-C to $120 million. The European Union actively supports the development of Ukrainian startups. The Seeds of Bravery initiative has allocated more than €20 million to support Ukrainian tech firms by providing grants of up to €60,000 to each startup company. As of March 2025, more than 60 startups have received funding in excess of €2 million.

Based on the annual review of the Dealbook of Ukraine [24], the Ukrainian tech investment ecosystem prepared by AVentures Capital, in 2024 the volume of investments in the Ukrainian tech sector increased by 120 % compared to 2023. According to the review, after a sharp drop in investment in the tech sector from $832 million in 2021 to $236 million in 2022, in 2023 the volume of investment amounted to $209 million. The recovery up to $462 million in 2024 shows Ukrainian technological industry is now halfway to returning to pre-war levels. In contrast, in 2024, as in the previous year, most of the funds – $223 million (48 %) of the total investment volume – were received at the late stages of financing. The overall picture may be changed by a significant deal with Creatio, a developer of a no-code platform for automating CRM and business processes. In the first half of 2024, this company raised about $200 million from a consortium of investors, including Volition Capital, Sapphire Ventures, and StepStone Group, which is a total of 90 % of Series C investments (made at later stages). In 2024, early-stage investments in projects totaling $147 million amounted to only 32 %. For comparison, they accounted for 39 % of the total investment in the tech sector in 2022 and 2023. In addition to the Creatio deal, the top five investment deals of 2024 included: a deal with the British fintech company Carmoola, in which VentureFriends QED, InMotion Ventures, and Investors contributed $19.2 million in January 2024; and IN1, a financial management application that integrates crypto-currencies and fiat money on one platform. At the same time, in September 2024, Brainstorm Ventures funded IN1 for $6 million. In addition, the Fintech Farm initiative, which creates neo-banks in developing countries in cooperation with conventional banks, received $5 million from Bank of Georgia this year (2024).

In 2024, Brave1 provided the largest number of grants to MilTech companies – $40 million, which plans to increase investments to $100 million in 2025. MilTech companies Bavovna.AI, Osavul, and Swarmer received significant funding ($2.8 million on average). The largest M&A deal of 2024, according to Dealbook, was the $1.5 billion acquisition of Datagroup-Vola and lifecell, the third largest mobile operator, by NJJ Holding. At the same time, the largest minority stake acquisition deals included the $7.7 million deal with Work.ua. KEUS, Grupa Pracuj, KUPR, and others are listed among the buyers. The largest mobile operator Kyivstar is among the likely M&A deals in 2025 with the purchase of the online taxi service Uklon. The deal is estimated at $80 million. In addition, Toptal acquired YouTeam, an online platform that allows companies to hire freelancers and software developers efficiently and quickly. Another noteworthy acquisition is CourtAvenue's purchase of BotsCrew, a developer of artificial intelligence chat-bots for business.

In 2025, the Ukrainian technological scene is surprising with its rapid growth and innovative developments that attract the attention of international partners. Among the most successful companies that have excelled this year are Jome (ex-NewHomesMate), a real estate platform that raised €9.3 million in January 2025; Portal AI, a startup that develops a marketing complex using artificial intelligence, received €4.75 million in investment in February 2025; and Esper Bionics, a startup that develops new generation prostheses, raised €3 million in March 2025.

Currently, there are 2118 active, proven technology companies in Ukraine. Approximately half of them are focused on services, 47 % are in outsourcing, and 3 % are in out-staffing. There are also 31 % of companies that focus on product development, and the rest use a mixed business model. Thus, technological development will be more effective within the framework of an ecosystem approach based on integration, interconnection, and focusing all activities on specific technological priorities within both traditional and new technology markets. In this context, it is advisable to use the "quick steps" method, which is manifested in the comprehensive coverage, clarification and use of possible support measures relevant to the technology sector.

Industrial enterprises face the challenge of adapting to change and integrating into developed ecosystems that can support their technological growth and provide access to advanced solutions and strategic resources. However, companies of different technological maturity levels face integration difficulties and need to transform their business models to successfully adapt – to respond quickly to changes in the technological environment and use the capabilities of the technological ecosystem. Therefore, it is important to develop an adaptive digital business model in the context of technological gaps and imbalances in industry potentials.

The concept of integration is the development of an approach that ensures the effective inclusion of an enterprise in the ecosystem, taking into account its technological and industry specifics. This concept is aimed at creating conditions under which an enterprise can successfully interact with other ecosystem participants, use available resources and infrastructure, and adapt its processes and products to market requirements and technological trends.

To successfully integrate into the technological development ecosystem, taking into account the technological profile and industry specifics, an important link is the positioning of the enterprise in the ecosystem. To choose a strategy for the integration and adaptation of enterprises to the tech ecosystem, we propose to use a matrix of management projects based on an assessment of the difference in technological capabilities of both the enterprise and the ecosystem as a whole (Figure).

The projection matrix allows an ecosystem participant to determine its own position in terms of technological maturity levels, target position, trajectory to achieve the goal, and choose integration strategies.

A technological profile is a comprehensive characteristic of the level of technological maturity, innovation potential, digitalization of an enterprise and the ecosystem, which reflects the ability to develop, implement, and adapt technologies, as well as the effective use of digital tools to achieve strategic goals. The technological profile may take into account a set of indicators, including the degree of process automation, readiness to integrate with external partners and ecosystems, and the availability of technologies that allow for goal realization.

To build a matrix of management projects, it is proposed to use an aggregate assessment of the level of technological potential (profile) by levels: low, medium, high. Consider the positional characteristics of the projection matrix (Table 1).

Cluster strategies are effective in positions where the ecosystem and enterprises have a sufficiently high level of technological maturity to support active interaction

Technological profiles levels		Technological profile of the enterprise		
		Low level	Medium level	High level
Technological profile of the ecosystem	Low level	S1	S4	S7
	Medium level	S2	S5	S8
	High level	S3	S6	S9

Fig. Management projection matrix: integration strategies

and co-development of innovations. In the matrix, cluster strategies strengthen positions in quadrants *C*5, *C*6, *C*8, *C*9 and intensify cooperation, accelerate knowledge and technology sharing, and reduce research and development costs.

Regional, territorial, and global scaling is realized in quadrant *C*9, where enterprises and the ecosystem have a high level of technological maturity and management readiness. It provides conditions for ecosystem expansion, full technological and organizational compatibility of enterprises and the ecosystem. At this position, integration with higher-level ecosystems is possible.

The matrix allows one, based on the assessment of the target position of the enterprise, to build a trajectory of progress to a higher level of maturity – to choose an integration path that demonstrates the directions and stages of the enterprise's development, taking into account the level of technological profile and the level of the ecosystem with which it is necessary to integrate (Table 2).

Trajectories allow enterprises to build a strategy for gradual or intensive technological development based on the capabilities of the ecosystem and available resources.

In the context of digital transformation, it is necessary to find new digital opportunities for technological development. A digital business model helps businesses adapt to the new digital environment. The difference between digital and traditional business models is the "digital" way of generating revenue and doing business. The digital context has a significant impact on the trajectories of enterprises' integration into the ecosystem [25]. The aspects of influence include:

1) accelerating the adaptation and implementation of innovations through the use of digital technologies; accelerating cooperation and integration through access to digital platforms and the creation of a single digital space that simplify the interaction of participants in technological processes, accelerate the exchange of data and knowledge, technological solutions, and enable the formation of continuous integrated value chains;

2) ensuring flexibility and adaptability of strategies and business models. Digital technologies simplify the setup and scaling of business processes, reduce or eliminate barriers to entry into the ecosystem, allowing for the equalization of technological potentials and the achievement of higher levels;

3) reduction of dependence on physical resources, physical boundaries of enterprises, geographical and

Table 1

Projection matrix positional characteristics

Technological projections	Features
Basic (incremental) adaptation (S1)	Minimum viable integration, focus on local adaptation to reduce costs and increase operational efficiency in order to maintain a competitive position or maintain a minimum viable level (liquidation, downsizing, winding down). Companies often decide to liquidate, downsize or wind down their operations at this point
Learning and adaptation (S2)	Integration into the innovation environment through cooperation and training, mentoring and innovation consultancy, and gradual adaptation to the average level of technology. This is also the minimum viable integration to ensure survival and accumulation of resources for development
Technological convergence with infrastructure support (S3)	Minimal integration strategy using ecosystem technologies: integration into promising innovation chains of ecosystem suppliers, purchase of technologies from a donor. This is a systemic adaptation of an enterprise in an advanced technological environment by using ecosystem resources
Localized technological optimization (S4)	Development of internal competencies, use of their own resources and local ecosystem solutions to improve the technological level through technology transfer to maintain a minimum competitive level in the face of limited innovation and ecosystem resources
Synergistic adaptation (S5)	Joint development of technologies with ecosystem participants, focus on synergistic interaction, as well as integration into innovation (technological value) chains as a donor, recipient, partner, and participation in cluster initiatives
Integration strengthening (S6)	Strategic cooperation, merger of competencies, joint ownership and use of assets and resources, interaction with key players to accelerate technological development and strengthen positions in the ecosystem (cluster strategies)
Local innovation leadership (S7)	The enterprise implements technologies on its own using internal resources and becomes a driver of innovation in the ecosystem, initiating and developing technologies at the local level, becoming a donor in the innovation transfer chain
Accelerated innovation integration (S8)	Proactive integration, including active participation in joint projects, technology transfer, and the creation and management of a value chain to grow strategic advantages (cluster strategies)
Co-leadership in innovations (S9)	Higher level of integration to create joint products and advanced innovative solutions. Integration occurs at the level of data, information exchange, processes, enhancing interaction, mutual learning of participants. It also includes integration into open innovation platforms, embedding in the innovation ecosystems of other territories, and the formation of strong networks and alliances that support long-term technological leadership (cluster strategies). This position determines the possibility of moving to a higher level - the level of ecosystem integration

Table 2

Possible projections of enterprise activity

Activity	Options
Organic growth trajectory	
Building competencies through systematic incremental improvements, focusing on training, borrowing core technologies, and partnerships with local players. In the long run, the enterprise can become a local technology leader that drives innovation in the ecosystem	*S*1–*S*5–*S*7 *S*1–*S*5–*S*8 *S*1–*S*2–*S*5–*S*8
Strategic cooperation trajectory	
The enterprise strengthens its position through strategic partnerships, launches and participates in joint projects and cluster initiatives, and integrates into advanced technology chains or global chains. The enterprise becomes an active participant in innovations, a donor, and the owner of key ecosystem competencies	*S*5–*S*6–*S*9 *S*5–*S*8–*S*9 *S*5–*S*9
Technological convergence trajectory	
The enterprise acts as a recipient and actively borrows and adapts technologies, implementing them to improve competencies. Subsequently, it builds its own technology chains, moving to cooperation and more active participation in the ecosystem	*S*3–S6 *S*3–*S*5–*S*6
Active innovation growth trajectory (accelerated innovation integration)	
The enterprise actively implements innovations through resource integration with partners in the ecosystem. It becomes an active participant in innovations, a donor, the owner of key ecosystem competencies, and a driver of ecosystem integration	*S*6–*S*9 *S*3–*S*6 *S*6–*S*8–*S*9
Adaptation and local leadership trajectory	
The enterprise actively develops internal competencies, stimulates technological changes, integrates into technological chains, and acquires technologies from a donor. It becomes a local leader and is ready to move to a higher level of development	*S*4–*S*8 *S*4–*S*7–*S*8 *S*4–*S*5–*S*8 *S*4–*S*5–*S*6–*S*8

territorial restrictions. Digital solutions, virtual borders, and mobile technologies weaken the power of physical borders and allow for global interaction, market expansion and partnerships regardless of location, the use of global resources and assets in addition to local resources, coordination of inter-organizational, cross-sectoral, cross-industrial, and international interaction, and control of integrated global technology chains;

4) reduction of transaction coordination costs due to low geographical barriers and high level of awareness;

5) reduced switching costs, the ability to quickly change business at a relatively low cost due to low search costs for accessible and comparable information;

6) increase in transparency of customer behavior and transparency of business activities, when customers, partners, and ecosystem participants receive more complete and high-quality information as their activities are monitored through digital channels;

7) increase in the availability of data for management, forecasting, and effective management decision-making.

The digital framework of the business model will make it possible to adapt business processes to the current technological profile, customize digital products and services for the ecosystem, optimize interaction and cooperation strategies, and set up monetization models adapted to the technological profile.

Let us consider some of the digital frameworks recommended in this study. Enterprises with a low level of technological maturity and digitalization can use the digital licensing model. The company implements licensed ERP or CRM systems or other technologies instead of developing its own system. Intermediate enterprises can use the digital platform sharing model, which allows them to integrate into ecosystem platform solutions and use resources and contacts.

Enterprises with advanced technological equipment are recommended to adapt a hybrid business model of monetization, which may include various sources of income, such as subscriptions, Freemium, and platform services [26]. For example, an IT company with high digital skills in the ecosystem can offer a SaaS service (Software as a Service) with a basic free version and advanced features for paid customers, as well as provide an API (Application Programming Interface) for integration with partner services for which payment is taken, which increases revenues and expands its presence in the system.

Enterprises with a developed technological profile are encouraged to adapt the model of cluster interaction. Digital clusters make it possible to share research costs and accelerate the introduction of new technologies.

Currently, smart manufacturing business models for high-tech enterprises in Industry 5.0 ecosystems based on the introduction of IoT, sensors and artificial intelligence technologies to create smart production processes have become very popular. The key features of the Industry 5.0 concept are the green and digital economy, as well as ensuring the stability and sustainability of the entire technological ecosystem [27]. For modern Ukraine, the formation of a smart nature of production is an important and necessary direction of post-war economic recovery.

The model of sustainable development and green technologies for enterprises with a high level of development allows sustainability-oriented enterprises to implement digital energy metering and management systems based on IoT and big data to reduce carbon dioxide emissions and increase energy efficiency [28, 29].

To increase the technological level of the ecosystem, different trajectories are permissible, which involve sequential or strategic progress through the matrix, where the ecosystem develops along with the technological growth of enterprises. Evolutionary development of the ecosystem through partnership adaptation (low ecosystem level and low/medium enterprise level) – the ecosystem level is increased by stimulating technology growth through partnership projects and interaction with enterprises with a high level of technological development. Acceleration development through the integration of advanced enterprises (medium ecosystem level and high enterprise level), where high-tech enterprises integrate into the ecosystem, gradually increasing its level through the introduction of advanced technologies, the exchange of best practices and the organization of educational, infrastructure projects, as well as infrastructure modernization. Leadership of high-tech enterprises to stimulate the ecosystem (high enterprise level and low ecosystem level), in which enterprises actively invest in the development of the ecosystem, stimulating its growth. Acceleration programs are supported, investments are made in educational and infrastructure projects, research and development centers are created, and new initiatives are implemented. Thus, we can see that digital business models can adapt enterprises of different technological levels and digital maturity to function effectively in the technological ecosystem and digital space.

Effective operation of an enterprise in the technological ecosystem requires the development of appropriate tools (Table 3). Implementation of these tools will contribute to the strengthening and development of an environmentally friendly, socially responsible, and economically successful technological ecosystem in Ukraine.

Building a strong technology ecosystem requires a balance between innovation and human resources. Technology is a powerful lever, but people are at the heart of every successful ecosystem. To enable industrial enterprises to develop new technologies, the focus should be on the effective use of professional qualifications and creative potential [30]. At the same time, the government should facilitate the creation and strengthening of these potentials by opening training centers, applying new approaches to technical and vocational education to meet the new needs of enterprises. In addition, a key factor in the development of these advanced digital production technologies is to increase the number of research institutes that deal with these technologies. Also, to build a strong technology ecosystem, enterprises should consider a number of talent development initiatives. These programs are important for bridging the gap between science and industry.

Conclusions. The results of the research allow us to specify the essence, structural elements of the technological ecosystem and their features, as well as to identify the most representative features of regional technological ecosystems that have already been formed or continue to transform. In this sense, a comprehensive approach is pro-

Table 3

A set of tools for effective functioning of the enterprise in the technological ecosystem

Factors	Management tools	Possible effects
Environmental sustainability	Monitoring of environmental impact. Implementation of environmental regulations, standards and certificates. Developing measures to preserve natural resources and protect ecosystems	Improving environmental protection policies and mechanisms. Limiting direct and indirect waste, reducing the amount of waste through technological platforms. Rational use of water resources and improvement of natural water quality. Ensuring reasonable use of resources. Highly efficient transmission of electricity with high capacity over long distances with reduced infrastructure requirements. Ensuring energy saving and energy recovery. Environmentally sustainable production. Growth of reputation, formation of an environmentally responsible image, access to new markets and customers
Social sustainability	Development of social responsibility programs. Implementation of training programs and professional development. Addressing social issues (combating poverty and inequality, ensuring access to education and healthcare, promoting the development of small and medium-sized businesses, etc.)	Improving the quality of employees' and local residents' lives. Reducing social tension. Strengthening the image and reputation
Economic sustainability	Developing long-term strategies (defining key performance indicators (KPIs) and goals, creating financing and investment mechanisms, searching for new markets and partners). Improving efficiency and productivity (optimization of production processes, better resource management. Development of new products and services. Exploring new market niches	Increasing profitability (cost optimization, productivity improvement, and market expansion). Creating new jobs (stimulating economic growth and developing innovative potential) Increased resilience to external shocks
Innovation sustainability	Strengthening research and development (R&D). Implementation of digital technologies. Digital transformation of business	Meeting market demand for innovative products and services. Optimizing production processes, reducing costs, and improving product quality. Creating new jobs
Interaction between ecosystem participants	Creation of cooperation platforms. Development of interaction between participants. Development of joint projects and initiatives	Strengthening synchronization and coordination of actions. Creating joint projects and innovations. Strengthening ties between ecosystem participants
Digital maturity	Use of programs and platforms to manage production processes. Development of digital platforms for ecosystem participants. Creating digital models and simulations to optimize production	Increased efficiency and productivity Increased transparency of production process management. New opportunities for generating innovations. Creating a viable plan for the digital transformation of enterprises and eliminating the digital divide at the micro and macro levels
Technological maturity	Marketing management procedures. Multifunctional and integrated teams. End-to-end information and analytical support. Measurable and standardized assessment of business process performance. Systematic multi-project planning and control of digital risks, consequences, and problems	Continuous analysis, modeling and automation of business processes to improve them. Increased flexibility, increased efficiency, early detection of potential risks (both fundamental and market, market and operational) and more accurate adjustment to changing customer needs, taking into account the consequences for the system. Implementation of advanced production technologies to ensure sustainable development

posed for successful technological development that harmonizes environmental, social, and economic goals, while encouraging innovation and interaction between ecosystem participants, and ensuring their digital maturity.

The practical results of the study are expressed in the identification of best practices in technological development that can be replicated and adapted in all other Ukrainian regions, taking into account their specifics. This will require the interaction of national and regional authorities aimed at intensifying the processes of creating and improving domestic technologies both in the priority areas of technological sovereignty projects and structural transformation of the country's economy, and based on the local needs of regional economies.

The task of ensuring a continuous flow of massive innovations as a key condition for accelerating technological development and strengthening the technological leadership of the domestic economy in the context of increased global competition and the negative impact of the war is urgent. To achieve technological breakthroughs, businesses need new business models that allow them to successfully integrate into technological ecosystems using digital technologies and develop through enhanced synergies. Digital business models are changing based on technological capabilities and industry specifics. The proposed methodological approaches to choosing ways to transform both enterprise business models and ecosystem business models can become an effective management tool in developing innovative strategies that lead to technological leadership.

The potential of technology ecosystems is tremendous. By collaborating together, the private sector, public sector, education, science, healthcare, and others can create a future where technology is used to solve society's most pressing problems. The most important thing in this is not to lose focus on achieving strategic goals. And now they are clearer than ever: our economic independence and stability, industrial strength, and ultimately Ukraine's victory in the war depend on the advanced development of technological ecosystems.

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Побудова технологічної екосистеми в умовах цифрової трансформації

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Мета. Обґрунтування науково-методичних і практичних розробок, що спрямовані на трансформацію національної технологічної екосистеми й наданні рекомендацій для впровадження адаптивної цифрової бізнес-моделі, орієнтованої на ефективну інтеграцію підприємств до технологічних екосистем.

Методика. У процесі дослідження використовувалися загальнонаукові методи: зіставлення, аналогії, аналіз і синтез, системний аналіз, методи багатокритеріальної оцінки й матричного моделювання. Для отримання результатів наукового дослідження були використані холістичний, мережевий і кластерний підходи.

Результати. Визначені пріоритети трансформації національної технологічної екосистеми й запропоновані рекомендації щодо прискорення її розвитку в напрямі формування сталих мереж взаємопов'язаних підприємств на основі передових технологій цифрового виробництва. Запропоноване нове розуміння сутності категорії «технологічна екосистема». Окреслені ключові особливості та складові технологічної екосистеми. Обґрунтовані принципи адаптації цифрових бізнес-моделей з урахуванням технологічних профілів як підприємств, так і екосистем, до яких вони інтегруються. Відповідно до рівня технологічної зрілості та цифрових можливостей підприємств та екосистем, запропоновані цифрові фреймворки, адаптовані до змін у технологічному просторі. Проаналізовані моделі й траєкторії інтеграції з урахуванням цифрового контексту. Розроблено інструментарій ефективного функціонування підприємств в умовах технологічної екосистеми. Означена перспектива просування практик менеджменту технологічних екосистем шляхом розробки інтегрованої моделі, що врівноважує екологічну, економічну й соціальну стійкість. Модель підкреслює важливість цифрової й технологічної зрілості, колаборації та інновацій як рушія адаптивності й стійкості екосистеми.

Наукова новизна. Розроблена адаптивна цифрова бізнес-модель, орієнтована на ефективне інтегрування підприємств до технологічних екосистем в умовах технологічних розривів і дисбалансів галузевих потенціалів. Запропонована матриця управлінських проєктів, за допомогою якої, на основі оцінювання технологічних (зокрема, й цифрових) рівнів, визначаються позиції підприємств і моделі інтеграції, що забезпечують підприємствам гнучкість в умовах цифрової трансформації. Упровадження інтегрованої моделі сприяє розвитку технологічного потенціалу екосистеми, активізації регіональних інновацій і досягненню синергічного ефекту в масштабах країни.

Практична значимість. Рекомендації можуть бути використані технологічними компаніями, менеджментом еко-індустріальних парків, фасилітаторами промислового симбіозу для розробки програмних, проєктних й інших довгострокових документів, що формалізують бізнес-модель, стратегію, політику розбудови національної технологічної екосистеми.

Ключові слова: *технологічна екосистема, цифрова бізнес-модель, інновації, логістика, комунікації, освіта, управління, технологічна зрілість*

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