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GLOBAL VIRTUAL HUB ECOSYSTEMS: GROWTH DYNAMICS AND NETWORK EFFECTS

The past decades have witnessed an unprecedented transformation of the global landscape, driven by the accelerated development of information technologies. Global virtual hub ecosystems hold a central place in this transformational phenomenon characterized by rapid growth and penetration into all spheres of human activity. These ecosystems, functioning exclusively in the digital dimension, have become an integral part of the modern economy and society, acting as central nodes that connect people, ideas, and resources on a global scale. The concept of a "hub" in this context extends beyond purely physical understanding, denoting a centralized digital node that facilitates complex interactions and exchanges among numerous, geographically distributed participants. These can be software platforms, architectural solutions, or sets of integrated digital services that enable millions of users to interact, collaborate, and conduct transactions without the limitations of the physical world.

The ecosystemic nature of such hubs underscores the deep interdependence among their components—end-users, developers, content providers, and service providers—who collectively create, exchange, and derive value [1]. Understanding these mechanisms is critically important for forming effective management strategies, developing appropriate regulatory frameworks, and stimulating innovation in this rapidly changing digital paradigm, as reflected in international initiatives such as the VE HUB4YOU (Virtual Youth Business Hubs International Network) project, implemented within the Erasmus+ program.

A virtual hub ecosystem can be conceptualized as a dynamic, interactive digital platform or a complex of interconnected digital services that perform the function of a central node for interaction, exchange, and cooperation among a diversified range of distributed entities—users, organizations, developers, and other digital entities [3]. The main characteristics that determine their essence are complete virtualization (the absence of physical presence in the traditional sense), high scalability, global accessibility, and an inherent ability to generate network effects. A typological classification of virtual hub ecosystems can be made based on their primary

functionality and intended purpose: these include social media hubs (e.g., Facebook, X (formerly Twitter)), e-commerce platforms (e.g., Amazon, eBay), developer communities and Open-Source platforms (e.g., GitHub), scientific and educational hubs (e.g., ResearchGate, Coursera), hubs for corporate collaboration and project management (e.g., Slack, Microsoft Teams), as well as media and entertainment hubs (e.g., YouTube, Netflix). Despite significant functional diversification, all these categories of hubs share common attributes that allow them to be considered as a single class of complex adaptive systems. The international VEHUB4YOU project is a prime example of an educational hub that connects youth, educators, and entrepreneurs for virtual knowledge and skill exchange.

The growth dynamics of global virtual hub ecosystems exhibit an exponential character, fueled by a complex set of interconnected mechanisms. Firstly, this includes the minimization of entry and usage barriers: the digital nature of hubs effectively removes geographical, physical, and often financial barriers that traditionally limited access to markets and services. Most platforms offer free or low-cost access to basic functionalities, which significantly contributes to mass user adoption, while intuitive interfaces and ease of use are also critical success factors. The VEHUB4YOU project clearly demonstrates this principle by providing youth from Eastern Partnership countries access to modern European business knowledge through virtual platforms, thereby lowering barriers to participation in business education. Secondly, global accessibility and scalability: thanks to ubiquitous Internet access, virtual hubs can reach audiences on a global scale. They are designed with high scalability, allowing them to support millions or even billions of users without significant performance degradation, thus enabling rapid expansion of operations without the need for substantial investments in physical infrastructure. VEHUB4YOU, aiming to create a network of 60 virtual business hubs and engage over 2500 participants, exemplifies this scalability. Thirdly, "snowball" effects: successful hubs often demonstrate organic growth driven by "word-of-mouth" mechanisms and personal recommendations. Satisfied users actively invite new ones, creating a powerful self-reinforcing growth cycle that can be more effective than traditional marketing campaigns. Fourthly, continuous innovation and updates: to maintain competitiveness and attract new users, virtual hubs constantly introduce new features, improve existing services, and optimize the user experience, which creates a sense of dynamism, relevance, and added value. VEHUB4YOU also focuses on improving educational programs in line with new trends in virtual learning. Finally, economic models that stimulate growth: many hubs employ innovative business models that directly encourage user base expansion, such as "freemium" models, advertising models, or commission-based models.

Network effects are a key explanatory factor underpinning the growth dynamics and value creation of virtual hub ecosystems. These effects arise when the value of a product or service for an individual user increases proportionally with the number of other users who utilize the same product or service. Two main types of network effects are distinguished. Direct network effects (one-sided) occur when the value of a hub to a user directly depends on the number of other users who also participate in the same network. A classic example is a telephone network; in the context of virtual hubs, this is clearly manifested in social networks, where the value of the platform for each user increases with the growing number of their connections, friends, or contacts on that platform, expanding potential interactions and communication opportunities. The VEHUB4YOU project, by creating a network of virtual business hubs, directly leverages direct network effects, as the value of participation for each student or educator increases with the growing number of other participants

and available mentors in the network. Indirect network effects (two-sided or multi-sided) arise in two-sided or multi-sided markets, where the value of a platform for one group of users increases with the increasing number of users in another group. For example, on an e-commerce platform, the value for buyers increases proportionally with the number of sellers, and vice versa—the value for sellers increases with the number of buyers. In the context of VEHUB4YOU, indirect network effects are demonstrated by the fact that a larger number of young entrepreneurs (one user group) attracts more business experts and mentors (another group), and vice versa, which increases the overall value of the ecosystem for all participants.

Positive network effects include the "attraction" effect, whereas the number of users grows, the hub becomes more appealing to new participants; an increase in content and functionality value, as user base growth correlates with increased content generation and improved algorithms; economies of scale, allowing hubs to reduce average costs per user; and standardization and compatibility, fostering the formation of de facto industry standards. The VEHUB4YOU project demonstrates these positive effects through the creation of a shared learning environment where the exchange of experiences and teaching methodologies enhances value for all partner universities and students. At the same time, there are also negative network effects and risks. Overload and quality degradation can occur with overly rapid growth. As data volume increases, challenges related to privacy and data security exponentially rise. Strong network effects can lead to market dominance and monopolization, limiting competition. Censorship and control of information flows become significant issues due to concentrated power. Finally, algorithms can inadvertently create "echo chambers" and polarization, reinforcing existing beliefs and fragmenting society. Although VEHUB4YOU, as an educational project, is less susceptible to commercial monopolization risks, issues of content moderation and ensuring inclusivity remain relevant for any virtual ecosystem.

Global virtual hub ecosystems exert a profound and multifaceted impact on contemporary socio-economic structures. They have contributed to the transformation of business models, leading to the emergence of the "sharing economy" and "gig economy," and radically reshaping traditional industries such as retail, media, and education [5]. Hubs significantly facilitate globalization and intercultural exchange, fostering deeper mutual understanding. The VEHUB4YOU project is a direct confirmation of this, promoting international exchange of business knowledge between the EU and Eastern Partnership countries. They function as powerful platforms for stimulating innovation and collaboration, providing environments for collaborative development and rapid dissemination of technologies. VEHUB4YOU directly contributes to this by updating curricula and creating methodological materials for online trainings [2]. In the sphere of social and political transformations, social media hubs have become influential tools for organizing social movements and political mobilization, although they can also be used for spreading disinformation. Finally, the rapid growth, transnational nature, and continuous evolution of these ecosystems create significant regulatory challenges at national and international levels concerning antitrust law, data protection, taxation, and determining responsibility for content.

The international VEHUB4YOU project serves as a vivid empirical confirmation of many theoretical provisions regarding the functioning and development of global virtual hub ecosystems. The main objective of the project is to transfer relevant business knowledge from EU countries to youth in Eastern Partnership countries (aged 13 to 30) through virtual exchange technologies. This initiative involves creating a network of international virtual business hubs and providing entrepreneurship education to schoolchildren, college students, and university students of both

economic and non-economic specialties [4].

The experience of VEHUB4YOU confirms that global virtual hub ecosystems are a powerful tool for expanding access to knowledge, developing skills, and stimulating entrepreneurial activity on a global scale, despite the potential challenges associated with managing such a large and diverse virtual network.

Effective understanding, adaptive management, and responsible regulation of global virtual hub ecosystems are critically important for shaping an inclusive, innovative, and sustainable digital future. The VEHUB4YOU project serves as a valuable case study for further empirical research in these areas.

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