Navigating Ecosystem Virtuality

An Integrative Perspective on Digital and Colocated Collaboration for Innovation

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1. Introduction

Addressing future challenges by means of innovation requires organizations to work together to a much larger degree than today, requiring both physical ('colocated') and digital collaboration. This collaboration for innovation often goes beyond single organizations and results in networks of shared value creation of different actors such as companies, research institutions, or supporting actors. These ecosystems of innovation transcend geographical and organizational boundaries and are enabled by the use of virtual tools. Consequently, activities between actors in *innovation ecosystems* comprise colocated as well as digital collaboration – or coined differently, involve both 'bricks & clicks' (Klimas/Czakon 2022).

The hybrid nature of collaboration in ecosystem-based innovation efforts is unsurprising given the complexity stemming from various interdependent elements such as actors, activities, artifacts, institutions, and the dispersed relations among them (Granstrand/Holgersson 2020). Technological innovation, in particular, requires the collaborative elaboration of diverse expertise and resources rarely colocated in one physical place. For instance, Mazzucato and Robinson illustrate how NASA's decades-long shift in the low-earth-orbit industry from being integrated in-house toward a dispersed multi-actor ecosystem has paved the way for innovation (Mazzucato/Robinson 2018), encompassing the use of virtual tools as well as colocated interactions (Mazhari et al. 2017). In fact, today's status quo of interorganizational work regularly involves the converging use of virtual tools in the form of enterprise social media, enterprise resource planning systems, cloud-based collaboration tools, project management solutions, or shared digital twins.

The recent global pandemic has further catalyzed digital collaboration in innovation ecosystems, notwithstanding the geographical proximity of its actors, and in the process, exposed the benefits and pitfalls of virtual tools (Faraj et al. 2021). A crucial ensuing question for ecosystem actors that we follow in this article then pertains to a potential balance between colocated and digital collaboration, and equally important, how this spectrum can be conceptualized and operationalized.

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Several distinct streams of literature offer initial insights for a continuous understanding of colocated and digital collaboration. First, the notion of *connectivity* (Kolb 2008) and *socio-materiality* (Orlikowski/Scott 2008) provide theoretical grounds for the presumption that the use of technology in and around organizations should be viewed on a spectrum and not in dichotomous terms (e.g., face-to-face vs. digital). Second, more specific frameworks in management literature regarding *virtual work* (Raghuram et al. 2019) or *digital internal communication* (Wuersch et al. 2023) give nuance to the involved levels of analysis and related concepts (e.g., digital platforms in organizations). Third, the multi-dimensional concept of *virtuality* (Kirkman/Mathieu 2005) in organizational literature falls into this tradition and has found repeated empirical application, however, mainly at the team level (Purvanova/Kenda 2022). Fourth, and lastly, ecosystem-specific research remains vague about the role of digital technologies for, in, and from ecosystems and resorts to discrete representations in terms of *digital innovation ecosystems* (e.g., Wang 2021) or *regional innovation ecosystems* (e.g., Radziwon et al. 2017). Taken together, each research stream affords a valuable perspective in itself, yet with no concept available that can be applied at the ecosystem level which allows for a continuous view (i.e., degrees) of employing virtual tools across actors.

Our article is set out to capture the spectrum between colocated and digital collaboration in innovation ecosystems by introducing the concept of *ecosystem virtuality*. Specifically, we translate the established concept from research on team effectiveness to the ecosystem level and look at the degree of *technology dependence*, in*formational value*, and *temporal dispersion*. Following the seminal works of Kirkman and Mathieu (2005), we define ecosystem virtuality as *the extent to which ecosystem actors rely on virtual tools to engage in collaboration, the amount of informational value provided by such tools, and the temporal dispersion of actors' collaboration*. Furthermore, we integrate related but so far disjointed insights from the literatures of organizational studies, ecosystem research, as well as technology and innovation management. Upon this integrative perspective, we propose key antecedents of ecosystem virtuality such as geographical dispersion, boundary conditions such as the level of trust among actors, and how these factors influence innovation.

Our conceptual contribution offers a pathway to operationalize and measure the degree of colocated and digital collaboration beyond single organizations, and therefore, allows for future empirical work to investigate potential optima of virtuality in innovation ecosystems. A resulting degree of ecosystem virtuality is independent of the specific tools in use and can thus account for the rapidly evolving landscape of virtual tools in (inter-)organizational practice. Assessments of ecosystem virtuality will enable the involved actors to make better-informed decisions for adequate means and modes of virtual tools for ecosystem-wide collaboration. For instance, ecosystem infrastructure such as *innovation hubs* (Haukipuro et al. 2023) can be set up physically, virtually, or in between, and emerging ecosystem instances of the so-called *industrial metaverse* are interfacing the physical and digital space by design while the scope of applications is still evolving (Li et al. 2023).

In perspective, knowing and understanding the *degree* of virtual tool use among actors in an innovation ecosystem is imperative for its involved actors to find a balance when collaborating in the physical and digital world.

The remainder of this article is structured as follows. In the subsequent section, we establish the theoretical premises and relatives of ecosystem virtuality. Next, we conceptualize ecosystem virtuality along its three dimensions, i.e., technology dependence, informational value, and temporal dispersion. We follow this with an integrative perspective on relevant antecedents, boundary conditions, and how ecosystem virtuality relates to innovation. Finally, we discuss the potential implications and directions for future research ahead of our concluding remarks.

2. Differentiating Theoretical Backgrounds

Understanding collaboration in innovation ecosystems as a convergence of virtual tool use and colocated interactions invoke distinct streams of research. In what follows, we draw from several research disciplines related to this phenomenon, first, by outlining the influence of digitalization on innovation ecosystems, and second, by describing the concept of virtuality from organizational literature.

2.1. Innovation Ecosystems in Digital Contexts

In complex business environments, the pursuit of innovation has transitioned from the solitary endeavor of individual organizations to a collaborative effort characterized by complex relationships among multiple actors. The increasingly decentralized and networked nature of innovation is reflected by the popularized metaphor of *ecosystems* in management research and practice (Adner 2006; Cobben et al. 2022). Specifically, *innovation ecosystems* are commonly defined as "the evolving set of actors, activities, and artifacts, and the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors" (Granstrand/Holgersson 2020, p. 3).

The boundaries of innovation ecosystems develop from a joint "value proposition through collaboration" (Autio/Thomas 2022, p. 17). Collaboration in this context can be understood as mutually supportive interactions (Castañer/Oliveira 2020). The specifying qualifier 'digital' primarily involves the use of virtual tools irrespective of the actors' geographical locations (e.g., cloud-based communication suites), and 'colocated' refers to collaboration occurring within close physical proximity without using virtual tools (e.g., co-working spaces). However, this distinction has become blurred in ecosystems due to the all-pervasive and advancing plethora of virtual tools.

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Digitalization has had a profound impact on innovation ecosystems. Prominently discussed influences include *digital innovations* embedded within and stemming from ecosystems (e.g., Nambisan et al. 2019; Wang 2021) as well as the evolving *governance and orchestration* of ecosystems (e.g. Hölzle et al. 2022; Kindermann et al. 2022). Related research on collaboration in *inter-organizational relationships* (Majchrzak et al. 2015) provides a complementary perspective, e.g., concerning virtual collaboration effectiveness (Zhang et al. 2018) or information sharing practices (Lee et al. 2021).

Despite manifold insights into these topics, previous research has fallen short of addressing the implications of virtual tools for *ecosystem-wide collaboration*. Recent reviewing works on the digital transformation have therefore emphasized the need for future research at the ecosystem level in this regard (e.g. Dąbrowska et al. 2022; Vial 2019). A potential reason for the previous paucity of ecosystem research on digital collaboration and related concepts such as communication, coordination, or cooperation (Castañer/Oliveira 2020) lies in more apparent levels of analysis such as teams, projects, organizations, or platforms. However, given that actors coalesce around a shared value proposition in innovation ecosystems, collaboration is not bound to these levels but happens across and between them, enabled by virtual tools.

2.2. Virtuality in Theory and Empirical Research

Virtuality implies a ubiquitous influence of digital technologies for collaboration, theoretically informed by the perspectives of connectivity, socio-materiality, and socio-technical systems. Each strand contributes an important aspect to our theoretical perspective on virtual tool use in ecosystem collaboration practice.

In organizational studies, *connectivity* refers to "a metaphor that highlights the complexities, interconnected processes and synchronized activities" (Angwin/Vaara 2005, p. 1448) of interactions within and across organizations, incorporating a social and technical dimension (Kolb 2008). Important for the context of dispersed ecosystems, research on connectivity gives insight into potential tensions and paradoxes (Kolb et al. 2020), thereby suggesting an *optimal degree* of virtuality which spans organizational and geographical boundaries.

The closely related notion of *socio-materiality* emphasizes how social and technological phenomena are inseparable in today's organizational reality of digitally-enabled work practices (Orlikowski/Scott 2016). At an aggregate level, the adjacent term *socio-technical system* is defined as the "[r]ecursive (not simultaneous) shaping of abstract social constructs and a technical infrastructure that includes technology's materiality and people's localized responses to it" (Leonardi 2012, p. 42). Scholars across disciplines have employed the socio-material and socio-technical lens to abstract our comprehension of the human-technology relationship toward generalizable mechanisms and patterns.

For instance, Malhotra and colleagues recently curated a special issue on the topic of 'socio-technical affordances for large-scale collaborations,' concluding in their introductory review that "research needs and insights related to technology-enabled forms of large-scale organizing will grow in the coming decade" (Malhotra et al. 2021, p. 1388).

Virtuality research so far has been focused on empirically validating the concept in teams and organizations (Raghuram et al. 2019), laying the groundwork for a further translation to ecosystems.

At the team level, research conceptually shifted from categorizing teams as virtual vs. colocated to degrees of virtuality (Dixon/Panteli 2010), "given that most organizational teams can to some extent be considered virtual" (Gilson et al. 2015, p. 1317). A widely adopted definition introduced by Kirkman and Mathieu depicts virtuality along three dimensions as "the extent to which team members use virtual tools to coordinate and execute team processes, the amount of informational value provided by such tools, and the synchronicity of team member virtual interaction" (Kirkman/Mathieu 2005, p. 700).

Meta-analytic findings show that team virtuality features a curvilinear relationship with information sharing (Mesmer-Magnus et al. 2011), that virtuality positively moderates the relationship between the level of trust and effectiveness in a team (Breuer et al. 2016), but also, that team virtuality does not directly predict team effectiveness (Purvanova/Kenda 2022). In essence, while virtuality plays a substantial role in teamwork, its influence on team effectiveness is mixed and contingent on several other factors. This ambivalent role of virtuality for teams prompts Purvanova and Kenda (2022) to point to the *virtuality-as-paradox* perspective (see also Purvanova/Kenda 2018), acknowledging the simultaneous benefits and pitfalls of virtual tool use.

At the organizational level, virtuality has been discussed only tangentially in the context of *virtual organizations* (e.g., Shekhar 2006). Riemer and Vehring (2012) observe an incoherent body of knowledge and use of the term virtual organization, but identify defining criteria such as a project orientation, focus on value creation, and a prevalent network structure. The authors further classify types of virtual organizations, of which the closest resemblance to ecosystems can be found in 'networked virtual organizations' (Riemer/Vehring 2012). Accordingly, the networked virtual organization is characterized by a collaborative inter-organizational network of actors who realize synergies linked through virtual tools, and interestingly, *trust* as "the key enabler of collaboration, which points to the importance of social relationships in the network" (Riemer/Vehring 2012, p. 272).

Bringing together the above, the concept of virtuality builds upon rich theoretical strands which share the premise that digital technologies and collaboration have become inseparable over the last decades and can result in paradoxical tensions.

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The empirical focus has been the team level of analysis with findings indicating important contingent factors such as trust. We build upon these insights for our following conceptualization of ecosystem virtuality.

3. Conceptualizing Ecosystem Virtuality

In this section, we define virtuality as an aggregate property of ecosystems and elaborate on its underlying three dimensions based on the foundational works of Kirkman and Mathieu (2005). Accordingly, we define ecosystem virtuality as *the extent to which ecosystem actors rely on virtual tools to engage in collaboration, the amount of informational value provided by such tools, and the temporal dispersion of actors' collaboration.*

It is worth noting that there is no general scholarly consensus on the dimensions of virtuality, reflecting its various manifestations in different contexts at different levels. Nonetheless, Raghuram et al. (2019) and others have identified technology dependence, temporal dispersion, and an informational facet as commonly adopted core dimensions of virtuality (see also, Bell et al. 2023). Discrepancies mainly arise from the question of whether *geographical dispersion* qualifies as a dimension. We concur with Foster et al. that "[p]eople/teams that are co-located may use technology-mediated communication just as much as distributed people/teams" (Foster et al. 2015, p. 281). This renders geographical dispersion as an important antecedent of virtuality but not as an inherent definitional component (see also, Section 4.1). Further, inconsistencies in the literature usually stem from a context-specific empirical construct (e.g., for meta-analytic purposes) but commonly share the underlying premises of the theoretical concept. For our definition of ecosystem virtuality, we adhere to established conceptualization practice as outlined by Podsakoff et al. (2016) and elaborate on its underlying three dimensions in the following.

3.1. Technology Dependence

Knowledge-intensive collaboration has become inseparable from using virtual tools. The recent global pandemic has certainly accelerated and amplified this trend and led to the adoption of digital technologies at an unprecedented pace and scale (Amankwah-Amoah et al. 2021; Faraj et al. 2021). Despite evolving sentiments (e.g., technostress) or task-specific differences (e.g., remote work), the reliance on digital technologies represents an inherent definitional feature of virtuality (Raghuram et al. 2019). Technology dependence has previously been specified as the *extent* of using technology-mediated interactions in terms of its proportion to face-to-face interactions, operationalized by the relative *frequency* of use (e.g., Mesmer-Magnus et al. 2011; Schaubroeck/Yu 2017).

An ecosystem-wide dependence on technology for collaboration will be highly specific to the respective context and depend on other factors such as the nature of predominant tasks, or the availability of digital and physical infrastructures (for

our discussion of boundary conditions see Section 4.3). Further, different ecosystem actors and subsets of actors will exhibit varying degrees of technology dependence. Still, the overall degree to which actors of an ecosystem rely on digital technologies in their collaboration toward joint value creation can be reflective of an aggregate level of ecosystem virtuality. This becomes evident in practice with regard to boundary-spanning collaboration spaces such as innovation hubs (Haukipuro et al. 2023). Certainly, technology dependence will be closely related to the means and modes of interactions which is captured by the following dimensions of virtuality.

3.2. Informational Value

The informational value conveyed among collaborating actors emanates from the richness of information – e.g., text messages generally have a lower value, extended reality (XR) environments have a higher value, and face-to-face interactions typically hold the highest value. However, as Kirkman and Mathieu (2005) argue, informational value is eventually determined by how means of collaboration are adequate to the task at hand. As an example, engineers collaborating in the additive manufacturing industry would not benefit from discussing design models face-to-face but require CAD tools to this end (Kirkman/Mathieu 2005). Consequently, virtuality is also reflected by the characteristics of how information is conveyed, insofar that more valuable information results in lower levels of virtuality.

The overall extent of informational value conveyed in an ecosystem would represent the richness and adequacy of a host of involved virtual solutions and face-to-face exchanges, and therefore, reflects an important qualitative facet of overall virtuality. Although Raghuram et al. note that "such a nuanced approach to measuring virtuality is still rare in empirical virtual teams research" (Raghuram et al. 2019, p. 320), an operationalization at the ecosystem level could comprise assessments of subjective perceptions or an objectified index of the tools in use.

3.3. Temporal Dispersion

The temporal dispersion (also, 'synchronicity') of collaboration has become an omnipresent consideration for modern workplaces – e.g., when working from home, abroad, or when deciding to use a 'synchronous' face-to-face meeting or an asynchronous e-mail. Thus, this dimension of virtuality takes into account the extent of temporal dispersion between real-time and time-lagged modes of collaboration. Similar to the other dimensions it hinges on several context factors such as geographical dispersion, work schedules, or the nature of the task (Raghuram et al. 2019).

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An ecosystem-wide assessment of temporal dispersion holds important insight into the functioning of the ecosystem, that is, the resulting composite could give indications of predominant preferences regarding the communication culture among actors. For instance, more asynchronous collaboration practices would contribute to higher levels of overall virtuality regardless of geographical proximity.

4. Integrating Ecosystem Virtuality

We integrate concepts related to the emergence of ecosystem virtuality in a conceptual framework by drawing from virtuality and ecosystem literatures. An overview of the suggested antecedents, boundary conditions, and consequences is shown in Figure 1. In the following, we particularly highlight *geographical dispersion* as a determining antecedent of ecosystem virtuality, focus on *innovative performance* as the key consequence, and outline *trust* as a boundary condition that could shape the influence of virtuality on an ecosystem. Notably, we focus on these concepts at an aggregate level, however, each of which are multi-level by nature (e.g., trust) which holds implications for subsequent research designs.

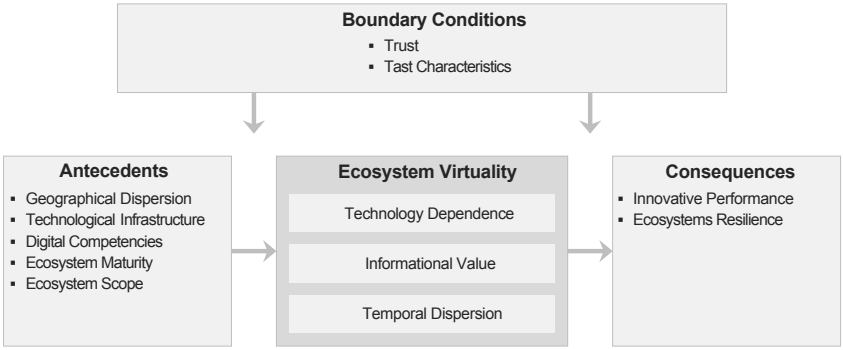

Figure 1: A Conceptual Framework of Antecedents, Consequences, and Boundary Conditions of Ecosystem Virtuality

4.1. Antecedents

Innovation ecosystems commonly comprise actors that contribute to a joint value proposition in spite of their geographical location. At the same time, innovation ecosystems often feature colocated actors such as in science and technology parks (Sandoval Hamón et al. 2022), and corresponding research on territorial innovation offers a wealth of insights into the benefits of spatial proximity (e.g., Howells/Bessant 2012). However, the post-pandemic work reality has become less bound to traditional conceptions of workplaces (Leone 2023), and thus, substantially increases spatial flexibility by leveraging virtual tools (Haefner/Sternberg, 2020). In one way or the other, we contend that *geographical dispersion* represents a

crucial determinant of ecosystem virtuality. We thereby follow previous lines of reasoning that geographical dispersion does not qualify as a definitional component of virtuality (e.g., Foster et al. 2015). For instance, colocated actors (e.g., an office apart) as much as distant actors (e.g., a continent apart) could equally rely on virtual tool use. Still, geographical distance can be indicative of higher levels of virtuality, and thus, constitutes an important and meaningful antecedent of ecosystem virtuality. Operationalizations of geographical dispersion in innovation studies usually entail network measures and have been applied in the study of innovation ecosystems as well (e.g., Still et al. 2014).

Several further contextual factors and characteristics of an innovation ecosystem should be considered as antecedents of its virtuality (for a similar rationale in teams, see also Kirkman et al. 2012; Kirkman/Mathieu 2005). In particular, *technological infrastructure* is essential for ecosystem virtuality, comprising the availability, access, and affordability of high-speed broadband networks (Lynn et al. 2022). Better technological infrastructure could eventually lead to lower levels of virtuality given the omnipresence of video-conferencing or progressing adoption of collaborative XR environments (see also Section 5.2). Furthermore, the level and distribution of *digital competencies* among ecosystem actors play a key role in realizing the potential of virtual tools (Oberländer et al. 2020). With respect to the characteristics of innovation ecosystems, their *scope* (e.g., in terms of their number of actors), and state of *maturity* are likely to influence their level of virtuality. Conceivably, innovation ecosystems that have progressed in their evolution could resort to higher degrees of virtuality subsequent to a formation phase (Dedehayir et al. 2018) which would require more colocated collaboration.

4.2. Consequences

The arguably most relevant outcome of an innovation ecosystem pertains to its collective *innovative performance* (Gomes et al. 2018; Granstrand/Holgersson 2020). This is typically assessed by the novelty, usefulness, and frequency of product, service, process, or systems innovations. We submit that the innovative performance of an ecosystem is substantially influenced by its aggregate level of virtuality. Furthermore, we argue that ecosystem virtuality and innovative performance exhibit an inverted U-shaped relationship, suggesting an optimum degree of virtuality. A theoretical rationale for this relationship can be found in the virtuality-as-paradox perspective (Purvanova/Kenda 2018), implying simultaneous challenges and opportunities arising from the use of virtual tools. For instance, Purvanova and Kenda (2018) illustrate this for team-level technology dependence in the form of 'touch tensions' (impersonal vs. less-biased interaction), 'data tensions' (data overload vs. informed decisions), and 'task tensions' (constant stress vs. intriguing work). This would also hold true in ecosystems, where on the one hand a lack of virtuality is often not feasible, and on the other hand, an over-pronounced use of virtual tools contradicts the collaborative co-creation of value in ecosystems.

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The degree of virtuality of an ecosystem could also have consequences for its overall *resilience*, that is, an innovation ecosystem's "ability to adapt to changes in the external environment" (Cobben et al. 2023, p. 5). Resilience has become a prominently discussed capability at various levels of analysis in the context of the global pandemic, including innovation ecosystems (Cobben et al. 2023; Könnölä et al. 2021). Further, digital technologies have been repeatedly discussed as an enabler of resilience (e.g., Xie et al. 2022) which we also ascribe to innovation ecosystems. Adequate degrees of technology dependence, informational value, and temporal dispersion can allow ecosystem actors to anticipate and respond to crises by making use of the right extent, means, and modes of colocated and digital collaboration.

4.3. Boundary Conditions

The emergence of ecosystem virtuality will be subject to boundary conditions (Busse et al. 2017) that influence the generalizability of the relationships we proposed above.

Particularly, we assert that *trust* among actors in an innovation ecosystem will serve as a boundary condition for how ecosystem virtuality can be harnessed toward innovative performance. A collective level of trust has been consistently identified as a key factor in collaborative arrangements such as inter-organizational relationships and virtual teams (Lascaux 2020) as well as innovation ecosystems (Steinbruch et al. 2022). For instance, realizing informational value by choosing appropriate means of collaboration (e.g., e-mail vs. face-to-face meeting) arguably depends on sufficient trust among actors. With regard to the role of trust as a boundary condition for the relationship of digital technology use and innovation, Barrane et al. (2021) conducted a qualitative study of a multi-stakeholder collaboration in new product development and conclude that "innovative organizations must adapt the emergent technologies, new practices and strategies that will support in developing an environment of trust and transparency between the different stakeholders" (Barrane et al. 2021, p. 217). We extend this proposed reciprocal relationship and propose trust to influence how innovation ecosystems can leverage an adequate degree of virtuality for their innovative performance.

Further potential boundary conditions stem from the predominant nature of tasks that are performed in an innovation ecosystem along its evolution (Dedehayir et al. 2018). Accordingly, we deem task characteristics such as type, complexity, interdependence, and required degree of collaboration as likely determinants for the manifestation of ecosystem virtuality.

5. Discussion

In the preceding sections, we have presented a novel conceptualization of ecosystem virtuality, outlined its key dimensions, and proposed potential antecedents, consequences, and boundary conditions. Further on, we discuss the implications of our conceptual framework, suggest potential directions for future research, and conclude with our final remarks.

5.1. Implications

Several theoretical contributions arise from our conceptualization of ecosystem virtuality. Initially, our work calls for a scaled understanding of virtual tool use in innovation ecosystems, and to this aim, bridges the so far distinct literatures on virtuality and ecosystem theory. We thereby respond to calls for a more nuanced consideration of the relationship between digital technologies and innovation eco-systems (e.g., Dąbrowska et al. 2022; Vial 2019). Further, we provide a continuous view between colocated and digital collaboration which has led previous ecosystem research to resort to distinct conceptualizations of digital or regional innovation ecosystems (e.g., Hölzle et al. 2022; Kindermann et al. 2022). Introducing the con-cept of ecosystem virtuality offers a way to capture nowadays convergence of dig-ital technologies and collaboration in ecosystems based on the theoretical premises of socio-material practices (Leonardi 2012). Furthermore, we build upon organi-zational research on virtuality and integrate this in our conceptual framework. Therein, we relate ecosystem virtuality to geographical dispersion as an antecedent, highlight innovative performance as a key consequence, and suggest trust among ecosystem actors as an important boundary condition for these relationships. Hence, we support the translation of established insights from organizational stud-ies on the influence of digital technologies (e.g., Wuersch et al. 2023) to research on innovation ecosystems.

The consideration of virtuality in innovation ecosystems carries various implications for their design, emergence, orchestration, and evaluation. First, designing innovation ecosystems would benefit from anticipating the dimensions of ecosystem virtuality, that is, the reliance on various digital technologies for collaboration as well as the required task- and actor-specific levels of conveyable informational value and temporal dispersion. In practical terms, acknowledging virtuality as an ecosystem property can inform balanced investment decisions for collaboration *infrastructure* such as science and technology parks (Sandoval Hamón et al. 2022) or innovation hubs (Haukipuro et al. 2023). Moreover, setting up innovation ecosystems for adequate degrees of virtuality could broaden their *inclusivity* and better accommodate remote actors from businesses, academia, policy, and society. Second, we argue that businesses engaging in ecosystem-based collaboration should carefully and strategically consider the degree of virtuality and corresponding benefits and pitfalls in the respective emerging innovation ecosystem (Budden/Murray 2022). Here, more digital collaboration with a broader pool of potential actors can

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strongly impact key business activities through more diversified knowledge sharing, greater international reach, and in turn, novel innovation opportunities. Third, the orchestration and governance of innovation ecosystems correspond closely with their digitally-enabled formal and informal structures and processes. For instance, insight into the manifestation of virtuality can aid ecosystem orchestrators in developing the resilience of an innovation ecosystem (Könnölä et al. 2021). Fourth, and lastly, assessing degrees of virtuality *across* innovation ecosystems can prove as a valuable criterion for *evaluative instruments* in policy-making, and eventually, inform decisions to enhance digital infrastructures (Lynn et al. 2022).

5.2. Future Directions

In light of our conceptualization of ecosystem virtuality and its implications, promising avenues for future research come into consideration regarding ecosystem theories, operationalizations, and the incorporation of advancing digital technologies.

While the scope of our article is geared toward innovation ecosystems, the notion of virtuality could also be employed for related ecosystem concepts. For instance, Wurth et al. have recently noted "a shift in the importance of geographical proximity (e.g., working from home, remote working, digital economy)" (Wurth et al., 2022, p. 758) for *entrepreneurial ecosystems*, calling for future research to address this observation. A virtuality perspective could help to further differentiate and specify the role of digitalization for entrepreneurial ecosystems (see also Zahra et al. 2023).

This article provides the conceptual grounds for operationalizing virtuality as a property of innovation ecosystems. Future empirical works could involve the internal and external validation of the construct and its underlying dimensions through qualitative and quantitative means. Further, our conceptual framework of ecosystem virtuality offers initial relationships that could be tested in case designs or correlational studies. An interesting question would be whether virtuality is best assessed as a composite of objective measures or could also involve *perceptions* of virtuality (similar to a recent perspective in teams research put forth by Handke et al. 2021).

Finally, the recent advent of user-friendly interfaces for generative artificial intelligence (AI) has put emphasis on the transformative role of AI not just for individual knowledge work, but also for collaborative innovation (e.g., Brem et al. 2023). This poses the question of how AI will be integrated with innovation ecosystem structures and processes, and eventually, how this phenomenon corresponds with ecosystem virtuality. A further prominently debated technology concerns the evolution of collaborative XR environments (e.g., digital twins) toward instances of the so-called 'industrial metaverse' (Li et al. 2023). While connected metaverse instances can be viewed as an ecosystem in itself (Schöbel/Leimeister 2023), the emergence of such boundary-spanning instances could also involve their relationship with established innovation ecosystems. XR-enabled metaverse instances

could score very differently across the dimensions of ecosystem virtuality, especially regarding their informational value, i.e., the richness and adequacy of the conveyed information. Hence, an important boundary condition worth exploring lies in the task-specificity of industrial metaverse instances. Applying the ecosystem virtuality lens would allow for a balanced approach to integrating industrial metaverse instances in innovation ecosystems.

5.3. Conclusion

Collaboration in present-day innovation ecosystems is neither purely digital nor always colocated but instead exists on a nuanced spectrum. To shed light on this phenomenon, we introduce the concept of ecosystem virtuality, a novel property of innovation ecosystems. Our article bridges established insights from organizational and ecosystem research as we translate virtuality to the ecosystem level and outline its theoretical premises and underlying dimensions. Further, we integrate ecosystem virtuality in a conceptual framework and highlight potential antecedents, consequences, and boundary conditions. Our conceptualization of ecosystem virtuality helps ecosystem actors navigate the intricate interplay of digital and colocated collaboration in innovation ecosystems and provides a way ahead for empirical validation.

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