A Boundary Crossing Perspective on Digital Industrial Platform Evolution

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Abstract - **Digital platforms have made their way to the mainstream state-of-the-art of many disciplines, propelled by their adoption across multiple industries. In the case of digital industrial platforms, the peculiarities of the industrial environments emphasize the iterative dynamics of cooperation and competition with complementors. By adopting a sociotechnical perspective that focuses on the interplay between platform owners and complementors, we explore how boundaries between complementors, and platform owners impact the transformation and evolution of platforms. We further conceptualize how the different phases of a digital industrial platform lifecycle follow recurring novelty cycles and how these are influenced by the alternance of collaborative and competitive boundary work with complementors. Leveraging this conceptualization provides a perspective on ecosystem governance focused on platform evolution. We use this conceptualization to explore how key performance indicators from a boundary object perspective serve to understand the need for new novelty cycles and guide the new functionalities that should be targeted. Finally, future avenues for research based on this conceptualization are suggested.**

Keywords - **Digital industrial platforms, platform evolution, boundary crossing, boundary object**

I. INTRODUCTION

Platforms have been a topic of research since the 1980s, with no end in sight for the platform economy [1] and the advancing of their ubiquitousness in all market sectors [2]. Digital Platforms (DP) leverage the ever-evolving availability and diversity of information technologies, combining and (re)configuring them in new ways to support and coordinate ecosystems of supply and demand [3]. In these environments, stakeholders on the demand side leverage platform-provided interfaces to co-create complementary products or services becoming platform complementors [3]–[5]. On the other side, end-users are the beneficiaries of these services, providing remuneration, data or other means of value in exchange [2], [3], [6]. By developing the technical and governance mechanisms, platform owners control and ensure the balance of authority against the autonomy of ecosystem actors [6], [7]. [2] point to three dimensions of platform governance: (i) decision rights, referring to how authority and responsibility for platform and complementary services decisions are divided among complementors and platform owner; (ii) control mechanisms, pertaining to how the platform owner excerpts direct control over complementors; and (iii) platform pricing policies. The continual orchestration of platform governance and architecture is crucial to ensure resilience and scalability on the short term and, on the medium to long time frames, deliver new novel functionalities not originally designed, while also integrating functionalities from adjacent markets [2], [3]. This constant transformation and adaptation to market needs is translated into a continuous evolution of the platform.

Throughout the years DP literature has been criticized by its conceptual ambiguity [7]. In inverting this trend, authors have begun focusing on the integration of DP in more specialized environments. [8] introduces the concept of Digital Industrial Platforms (DIP) as a subset of DP where: technical elements are composed by heterogeneous sets of industrial assets (physical or virtual); the ecosystem is composed by industrial organizations; and the marketplace is arranged for complex business-to-business environments [8]. While DP have amassed a varied and mature body of literature, DIP challenges many of the established propositions while presenting emerging questions of how platforms can thrive in industrial environments and how DIP ecosystems can be consciously designed and governed to better deliver value to organizations [8]–[10].

Another criticism of the broader DP literature is how it has adopted single paradigm perspectives, such as economic [1] and technical [2]. We argue that the more recent sociotechnical perspective [7] on platform ecosystems and ecosystem governance is crucial to understand the transformation and evolution of platforms over time. One such sociotechnical perspective pertains to the coordination and collaboration between different stakeholders involved in the evolution of the platform. Authors at the forefront of the conceptual work around platform ecosystems [3], [11]–[13] describe how complementor autonomy is crucial to understand ecosystem dynamics. While the influence of low and highly coupled partnerships has for long been studied by the management community, it is still not clear how the different types of complementors interact with the DP to increase (unprompted) changes and lead the transformation of platform core objectives, functionalities and ecosystem governance strategies [3]. These complementors possess different knowledge which needs to be integrated for the success of the platform [14]. However, this integration can be hindered by different types of boundaries, whose complexities are driven by the amount of novelty present in the phase of evolution [14]. The crossing of boundaries between the platform owner and complementors, implying the transfer, translation and transformation of knowledge across boundaries [14], subsequently becomes a crucial activity. The topic of boundary crossing has been covered in a plethora of areas such as pedagogics, innovation management and to a certain extent DP, showing the prominence and potential of the topic, which can provide a meaningful lens for DIP. In this paper we therefore adopt this sociotechnical paradigm of DIP to discuss how a boundary crossing perspective between platform owner and complementors can shed new light into platform governance and architecture to further support the constant evolution and transformation required to cope with changing market needs. By combining literature on DIP and boundary crossing, we first conceptualize how the different phases of the platforms' lifecycle trace recurring novelty cycles and how these are influenced by the alternance of collaborative and competitive boundary work, implying work at a boundary and work for boundaries, with complementors [15]. We then leverage this conceptualization to discuss possible applications and subsequent implications through the use of a boundary object perspective [14] on key performance indicators (KPI:s) for governance of DIP evolution.

II. EVOLUTION OF DIGITAL INDUSTRIAL PLATFORMS

As with most technological innovations, a DP lifecycle can be divided into four stages: an introductory stage that follows the initial design; an ascension stage, where, after initial deployment and with core services implemented the platform reaches a break-even point and starts to gather traction with the intended end users; a maturity stage; and a decline stage where services and functionalities start losing relevance and are no longer able to satisfy the evolving market needs [2], [16].

The technical nature of DP that allows for fast iterations (of architecture and governance) makes them particularly susceptible to the emergence of dominant designs that, over time, highly influence introductory lifecycle stages. [17] describe a high novelty phase when a particular solution first emerges and multiple competitors will experiment with different types of features and designs to address the same need. In time, these competing solutions eventually converge on a design that becomes widely accepted by both customers and producers, who become reluctant to deviate from the established architecture. This process is further compounded by [12] that describe how the early innovation drive in a technology's development, guided by a drive to meet market requirements, changes to an innovation process mainly driven by competition among suppliers that are now faced with technologically satisfied consumers. The establishing of these dominant designs and the highly volatile environment of technical and process innovation, leads to intense market competition and requires platform owners to engage in highly novel transformation processes able to take platform functionalities further in line with market needs, reinforcing [18] vision for the need of designing sociotechnical systems that are in a continuous state of change.

[2] describes this capability of avoiding the decline phase as leapfrogging. By leapfrogging between successive mature and ascension stages, embracing the recurrence of cycles of novelty as means of transforming platform's core functionalities and even objectives and vision, the platform becomes better able to evolve and follow market trends. We envision this process as a transformative one, where platform owners steer the platform's architecture and governance models, to act as building blocks to satisfy new needs (with new core functionalities), while maintaining current user needs met.

Recently, authors such as [3], [11]–[13], [19] at the forefront of the conceptual work around platform ecosystems, suggest that focus should be placed on the inter-organizational economic, business, and social perspectives of ecosystems. In this effort, [3] describe how a platform's ecosystem is built by high and low-autonomy complementors. Complementors with a high autonomy are loosely coupled to the DP, highly independent and separate from the platform and the platform owner, contributing mainly to the variety and amount of complements [20]. Low autonomy complementors are tightly coupled, forming strategic partnerships [21], leading to high mutual trust between complementary and owner, that can take the form of commonly defined goals, and contracts [22]. While the influence of low and tightly coupled partnerships has for long been studied by the management community, it is still not clear how the different types of complementors interact with the DP to increase (unprompted) changes in platform core objectives, functionalities and ecosystem governance [3]. We argue that these interactions vary over time, with the different types of complementors having alternating levels of influence and engage in different types of boundary work [15] in the platform's life cycle stages according to (i) the level of novelty involved in each life cycle stage; and (ii) the need for collaboration and input from complementors. Additionally, this dynamic becomes increasingly important for DIP where tightly coupled complementors are crucial not only for the support the development of platform functionalities but also in exerting influence on customers and suppliers and leading new end users to be part of the platform ecosystem. As discussed by [23], different actors can engage in both cooperation and competition. In this sense, the goal is not necessarily to cross boundaries through collaborative boundary work, but rather engage in competitive boundary work to cement boundaries [15]. The initial introductory and ascension stages of a DP are highly novel stages where, following the initial platform design process, the platform owner relies heavily on collaborative boundary work [15] and input of tightly coupled complementors, rising from a need to work across the boundaries between the platform owner and the tightly coupled complementors. This is done to validate and iterate over initial design propositions in order to gain traction with both end users and the more loosely coupled

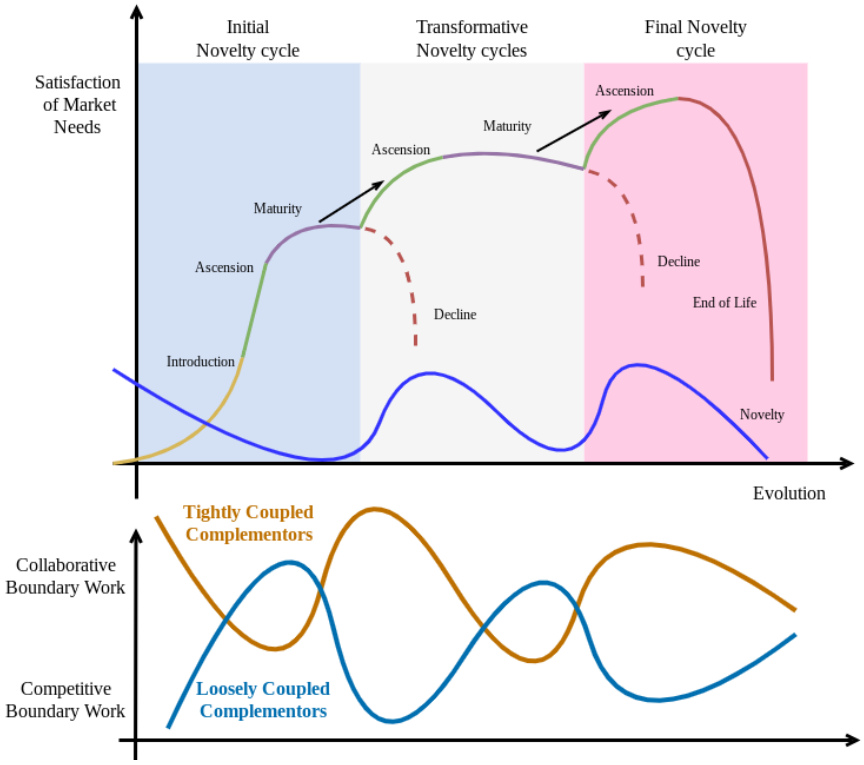

Fig. 1 DIP Evolution Through Iterative Novelty and Complementor Cycles Platform evolution cycles

complementors. On the other hand, the platform owner is not concerned to the same extent with the loosely coupled complementors in this phase, leading to competitive boundary work [15], implying a reduced influence from them. These phases compose the initial novelty cycle and are crucial for the short-term survival of the platform [2]. When a maturity stage is reached and the implemented set of core functionalities is cemented and able to satisfy the needs of the established ecosystem, the need for collaboration with tightly coupled complementors decreases and leads into more competitive boundary work [15]. On the other hand, the variety introduced by the loosely coupled complementors becomes crucial in avoiding a decline stage, shifting the type of boundary work into a more collaborative role. It gives the platform owner the visibility into how ecosystem actors (not directly influenced by the platform owner, as with tightly coupled complementors) leverage platform functionalities in novel, not initially foreseen ways, pointing to possible leapfrogging opportunities. Having identified a market need not satisfied by the current platform core functionalities, the platform owner needs to engage in a new novelty cycle to fill this gap. For this process, the platform can leverage new or existing tightly coupled complementors to anchor these new functionality against, thus triggering another alternance in tightly and loosely coupled complementor collaborative boundary work. We call these transformative novelty cycles which are characterized by recurring ascension and maturity phases, alternance in collaborative and competitive boundary work between tightly and loosely coupled complementors, and are tied together by the embracing of new platform functionalities. With the eventual decline of the platform, where the platform's core functionalities can no longer sustain changes that are able to satisfy the evolving market needs a final novelty cycle is reached leading to the platforms' end of life.

Figure 1 depicts our conceptualization of the platform evolution process as an iterative cycle that leverages the alternance of tightly and loosely coupled complementors to push for constant evolution as a means of driving innovation and avoiding declines in the satisfaction of market needs. In the following section we demonstrate how this conceptualization can be used to develop governance strategies for the evolution of DIP.

III. USE CASE OF CONCEPTUALIZATION FOR GOVERNANCE STRATEGY

While from a technical perspective, the ability to embrace new cycles of novelty to provide what can be radically different functionalities is ensured by the modularity of the platforms' architecture [2], two major challenges related to the governance of the evolution can be brought up: (i) how does the platform owner become aware of the need to embrace a new novelty cycle; and (ii) how does the platform owner decide where to leapfrog to, what new functionalities should be targeted and implemented. By using the previously presented model, we can shed some light on these matters by further looking into the role of KPI:s as boundary objects, which are objects that different groups can relate to and be used as a means to transfer, translate, and transform knowledge across boundaries [14].

To address the first challenge, the use of KPI:s can guide the platform owner in terms of how the platform satisfies current market needs but also point to paths for transformation. During the maturity phase where the novelty is low, specific KPI:s can be used as means to transfer knowledge [14] from the loosely connected complementors due to the more explicit characteristics of the knowledge and exploitation of the current platform functionalities [24]. These specific KPI:s can be used as a means of ecosystem control since they inherently focus on the performance of the core functionalities of the platform pertaining to its original intended purpose and functionality [17]. On the other hand, this way of working with KPI:s may subsequently lead to a lack of innovation since the perceptions and insights are limited to the original intended usage of the platform. Thus, there is also a need for more general KPI:s which are able to convey more tacit usage of the platform, in ways that were not initially foreseen. A subsequent effect of this is also that while the use of specific KPI:s allow for more collaborative boundary work [25] towards the platform ecosystem and loosely coupled complementors, they cement the boundaries and influence of the tightly coupled complementors, resulting in competitive boundary work towards them [15] since the incepted KPI:s are focusing mainly on the platform usage from the loosely coupled complementors point of views. From this collaborative boundary work and transfer of knowledge from the loosely coupled complementors towards the platform owner, the platform owner is able to understand the current platform's ability to satisfy market demands and further anticipate the advent of decline phases. This subsequently instigates the need for a new novelty cycle.

When addressing the second challenge and designing and adopting new functionalities by targeting a new ascension phase, the higher amounts of novelty bring with it a change in how KPI:s are used. When mainly concerning incremental changes and evolution, the type of boundary work and use of KPI:s explained earlier were sufficient since the amount of novelty was low. However, when leapfrogging, the amount of novelty is higher and the need of accessing more tacit usage and knowledge requires a boundary object which is more flexible, meaning that it can be altered and inhibit a higher level of interpretative flexibility [24]. Subsequently, having specific KPI:s is not satisfactory to allow for the manifestation of more tacit usage and knowledge and subsequent transformation and creation of new knowledge and platform functionalities [14]. Thus, more general KPI:s concerning the overall ecosystem play a bigger role in such phases. Higher novelty and subsequent complexity in the boundary being crossed is further more reliant on brokering, as brokers can support the KPI:s in functioning as boundary objects and further enable transformation of knowledge [26] which support the direction in terms of innovative new functionalities. This is manifested through a need of more collaborative boundary work [15] with the tightly coupled complementors where they can play the roles of brokers in order to create new novel solutions and directions for the evolution of the platform. Whereas dispersion between the loosely coupled complementors and platform owner is sufficient in low novelty phases and for incremental changes, the higher novelty demands higher intensity in the interactions between the platform owner and the highly coupled complementors where they meet and discuss. Pertaining to this, the KPI:s can serve as boundary objects through the combined use of the previously used specific metrics, providing insights into the previous behavior of the loosely coupled complementors, together with the more flexible set of general metrics which allows for more novel insights, thus showing the complementary role between different KPI sets as boundary objects [27].

IV. DISCUSSION AND CONCLUSIONS

[7] criticisms of conceptual ambiguity in DP research have, in the past years, pushed scholars to adopt new perspectives and to study platforms in different settings. The focus on DIP that comes out of this trend requires new ways of understanding the peculiarities of how industries as complementors and (supply and demand-side) end-users can leverage platforms and platform ecosystems to derive value for existing and new business processes. In this paper we propose a conceptualization of the evolution of DIP that, by focusing on the novelty introduced by each phase of a platform's lifecycle, reinforces [23] the idea of coopetition as an advantageous relationship for innovation. We argue that this alternate and simultaneous state of cooperation and competition between platform owner and tightly and loosely coupled complementors allows the necessary affordances for the platform owner to develop valuable platform core services, while also providing the tools to understand when and how to transform these services to better fit the ever-changing market needs. In term, this supports [18] vision that future sociotechnical system design should focus on the design of systems that are in a continuous state of change and transformation and that require a constant balance between organization, ecosystem, technical and social systems. We further use this conceptualization to discuss how it highlights questions crucial for the medium to long-term stages of platform evolution.

We point to how questions related to how platform owners perceive the need to embrace new novelty cycles and decide what new functionalities to embrace, can be supported by the use of KPI:s, suited for each platform lifecycle stage and complementor type. While the use of specific KPI:s and collaborative work with loosely coupled complementors is important in coming out of ascension stages in order to achieve and maintain the maturity of a platforms' functionalities in the maturity phase, leapfrogging and adaptation to new market needs requires a higher level of abstraction in KPI:s and collaborative work with tightly coupled complementors. Focusing not only on specific but also more general KPI:s that concern the overall ecosystem and how the more loosely coupled complementors leverage platform functionalities, is crucial to avoid declining stages where the platform is no longer able to fulfill a market's needs since it instigates new novelty cycles.

While this conceptualization provides us with a structured manner to look into a platform's iterative evolution path, several more questions can be posed and justify further research. First and foremost, the validation and application of the conceptualization with empirical data would be auspicious. While the lifecycle stages of technologies and DP in particular, as well as the influence novelty plays into them is a prominent topic of research, their validation for the DIP ecosystems is still an open question. Going further in the conceptualization application, questions from the business and sociotechnical perspectives can be raised: (i) How can the conceptualization presented in this paper be used to support the initial design of the DIP (ii) how do you choose highly coupled complementors; (iii) what hinders further leapfrogging? We see these questions as avenues for future research.

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REFERENCES

[1] G. Parker, M. Alstyne, and S. Choudary, Platform Revolution. New York, USA: W. W. Norton & Company, Inc., 2016.
[2] A. Tiwana, Platform ecosystems: Aligning architecture, governance, and strategy. Newnes, 2013.
[3] A. Hein et al., “Digital platform ecosystems,” Electron. Mark., vol. 30, no. 1, pp. 87–98, Mar. 2020
[4] H. C. Lucas and J. M. Goh, “Disruptive technology: How Kodak missed the digital photography revolution,” J. Strateg. Inf. Syst., vol. 18, no. 1, pp. 46–55, Mar. 2009
[5] R. Alt, W. Abramowicz, and H. Demirkan, “Service-orientation in electronic markets,” Electron. Mark., vol. 20, no. 3, pp. 177–180, Dec. 2010
[6] A. Ghazawneh and O. Henfridsson, “A paradigmatic analysis of digital application marketplaces,” J. Inf. Technol., vol. 30, no. 3, pp. 198–208, 2015
[7] M. de Reuver, C. Sørensen, and R. Basole, “The digital platform: A research agenda,” J. Inf. Technol., pp. 1–12, 2017
[8] T. Pauli, E. Fielt, and M. Matzner, “Digital Industrial Platforms,” Bus. Inf. Syst. Eng., vol. 63, no. 2, pp. 181–190, 2021
[9] A. Gawer and M. A. Cusumano, “Industry Platforms and Ecosystem Innovation,” J. Prod. Innov. Manag., vol. 31, no. 3, pp. 417–433, 2014
[10] H. D. Silva, M. Azevedo, and A. L. Soares, “A Vision for a Platform-based Digital-Twin Ecosystem,” IFAC-Pap., vol. 54, no. 1, pp. 761–766, 2021
[11] R. Kapoor, “Ecosystems: broadening the locus of value creation,” J. Organ. Des., vol. 7, no. 1, p. 12, Oct. 2018
[12] R. Adner and D. Levinthal, “Demand Heterogeneity and Technology Evolution: Implications for Product and Process Innovation,” Manag. Sci., vol. 47, no. 5, pp. 611–628, May 2001
[13] M. G. Jacobides, C. Cennamo, and A. Gawer, “Towards a theory of ecosystems,” Strateg. Manag. J., vol. 39, no. 8, pp. 2255–2276, 2018
[14] P. R. Carlile, “A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development,” Organ. Sci., vol. 13, no. 4, pp. 442–455, Aug. 2002
[15] A. Langley, K. Lindberg, B. E. Mørk, D. Nicolini, E. Raviola, and L. Walter, “Boundary work among groups, occupations, and organizations: From cartography to process,” Acad. Manag. Ann., vol. 13, no. 2, pp. 704–736, 2019.
[16] C. M. Christensen, “Exploring the limits of the technology S‐curve. Part II: Architectural technologies,” Prod. Oper. Manag., vol. 1, no. 4, pp. 358‐366, 1992.
[17] P. Anderson and M. L. Tushman, “Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change,” Adm. Sci. Q., vol. 35, no. 4, pp. 604–633, 1990
[18] W. Pasmore, S. Winby, S. A. Mohrman, and R. Vanasse, “Reflections: Sociotechnical Systems Design and Organization Change,” J. Change Manag., vol. 19, no. 2, pp. 67–85, Apr. 2019
[19] A. Hein, M. Schreieck, M. Wiesche, M. Böhm, and H. Krcmar, “The emergence of native multi-sided platforms and their influence on incumbents,” Electron. Mark., vol. 29, no. 4, pp. 631–647, Dec. 2019
[20] K. J. Boudreau, “Let a Thousand Flowers Bloom? An Early Look at Large Numbers of Software App Developers and Patterns of Innovation,” Organ. Sci., vol. 23, no. 5, pp. 1409–1427, Oct. 2012
[21] E. Danneels, “Tight–loose coupling with customers: the enactment of customer orientation,” Strateg. Manag. J., vol. 24, no. 6, pp. 559–576, 2003
[22] H. K. Steensma and K. G. Corley, “On The Performance Of Technology-Sourcing Partnerships: The Interaction Between Partner Interdependence And Technology Attributes,” Acad. Manage. J., vol. 43, no. 6, pp. 1045–1067, Dec. 2000
[23] M. Bengtsson and S. Kock, “Coopetition” in Business Networks—to Cooperate and Compete Simultaneously,” Ind. Mark. Manag., vol. 29, no. 5, pp. 411–426, Sep. 2000
[24] K. U. Koskinen, “Metaphoric boundary objects as co-ordinating mechanisms in the knowledge sharing of innovation processes,” Eur. J. Innov. Manag., 2005.
[25] S. F. Akkerman and A. Bakker, “Boundary crossing and boundary objects,” Rev. Educ. Res., vol. 81, no. 2, pp. 132–169, 2011
[26] V. Merminod and F. Rowe, “How does PLM technology support knowledge transfer and translation in new product development? Transparency and boundary spanners in an international context,” Inf. Organ., vol. 22, no. 4, pp. 295–322, 2012.
[27] H. Scarbrough, N. S. Panourgias, and J. Nandhakumar, “Developing a relational view of the organizing role of objects: A study of the innovation process in computer games,” Organ. Stud., vol. 36, no. 2, pp. 197–220, 2015.