Socio-technical Complexity in Digital Platforms

The Revelatory Case of *Helix Nebula – The Science Cloud*

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Abstract

(a) **Situation faced**: The digitalization case reported here refers to the digital platform *Helix Nebula – The Science Cloud*. Early after the go-live in 2014, *Helix Nebula* aimed to compete with leading digital platforms such as those of *Microsoft* and *Alphabet*. To this end, *Helix Nebula* extended its scale and scope of inter-organizational collaboration toward a digital ecosystem. In effect, four leading European information technology (IT) providers started cooperating with partners over a shared digital platform to deliver cloud services to client organizations. Value-destroying high levels of socio-technical complexity resulted. This complexity increasingly inhibited the digital platform *Helix Nebula* from thriving and growing.

(b) **Action taken**: *Helix Nebula* implemented four consecutive and interrelated actions to counteract complexity. *First*, it modelled its digital ecosystem entailing platform owners, partners, clients, and subcontractors. *Second*, it agreed on a shared understanding of socio-technical complexity comprising four constituents: structural organizational, dynamic organizational, structural IT, and dynamic IT complexity. *Third*, it identified manifestations of these constituents in its digital ecosystem. *Fourth*, it took according countermeasures to reduce these manifestations. While two countermeasures (*orchestration* and *standardization*) reflect the need of maintaining organizational and technological integrity, the other two (*autonomization* and *modularization*) reflect the need of maintaining organizational and technological elasticity in digital ecosystems.

(c) **Results achieved**: *Helix Nebula* has reduced its digital ecosystem's socio-technical complexity to value-adding levels. This reduction contributed to realizing three interrelated improvements. First, *Helix Nebula* has scaled more effectively from initially ten partners to currently 40. Second, *partly* owing to reduced socio-technical complexity, *Helix Nebula* has improved its efforts in *co*-creating value through more effectively exchanging, adding, and even synergistically integrating resources. Third, in implementing the countermeasures against socio-technical complexity, *Helix Nebula* has developed four capabilities for facilitating digital platform permanence. These capabilities deal with the intricacies of digital ecosystems that substantially complicate digital platforms' state of continued existence.

(d) **Lessons learned**: *First*, facing considerable challenges in analyzing its evolving digital ecosystem, capturing all dimensions and characteristics of socio-technical complexity in digital platforms proved intricate. In effect, *Helix Nebula* managers have favored the parsimonious and succinct framework presented in this work conversely. *Second*, *Helix Nebula* managers adopt an ambidextrous approach to reducing complexity. That is, successful digital platforms balance (i) top-down, central *control* imposed by platform owners and (ii) bottom-up, decentral *generativity* imposed by platform partners, clients, and subcontractors. *Third*, complexity in digital platforms can pose both *good effects* (enabling, rewarding, value-adding, required, desirable) and *bad effects* (constraining, unrewarding, value-destroying, unrequired, undesirable).

1. Introduction

This case description sheds light on socio-technical complexity as *one* reason for weak scaling, inhibited value co-creation, and fugacious existence of digital platforms. The overarching goal of this case description is thus to provide practical guidance in *reducing* socio-technical complexity of an implemented digital platform. As such, while the case description at hand does *not* offer a method on how to *launch* a digital platform, it aims to offer practical guidance on how to reduce socio-technical complexity in any given digital platform. Specifically, the digitalization case reported here refers to *Helix Nebula—The Science Cloud*, an exemplar of a digital platform (Reuver et al. 2017). *Helix Nebula* was founded during a three-year pilot phase from 2011 to 2013. It has grown out of a pioneering European public-private partnership between leading information technology (IT) providers (e.g., Atos, SAP, and T-Systems) and Europe's biggest research centers (e.g., CERN, EMBL, and ESA). *Helix Nebula* has been established to build a multidisciplinary digital ecosystem for data-intensive, large research organizations. Its digital self-service marketplace denoted *HNX* facilitates the marketing of *Helix Nebula*'s cloud computing services. By means of an innovative broker technology, *Helix Nebula* aims to deliver easy and large-scale access to a range of commercial cloud computing services (e.g., storage, processing, or high performance computing). Target groups are both publicly-funded as well as commercial organizations of diverse sectors (e.g., healthcare, oil and gas, financial, high-tech, and manufacturing). From the outset, *Helix Nebula* aspired to compete with digital platform incumbents such as *Microsoft*. Consequently, it aimed to extend its scale and scope of inter-organizational collaboration toward a loosely-coupled digital *ecosystem*.

However, while the needs of *Helix Nebula*'s target group's IT were and still are underserved and first client organizations were satisfied with their pilot use cases, *Helix Nebula*'s initially targeted levels of scaling, value *co*-creation, and platform permanence were significantly inhibited. The intricacies and constraints imposed by socio-technical complexity (Xia and Lee 2005), *one* reason for digital platform failure (Hanseth and Lyytinen 2010; Tiwana 2015; Reuver et al. 2017), contributed to this disillusioning episode. In what follows, socio-technical complexity refers to the "*state of consisting of many varied organizational and technological elements that are interrelated and change over time*" (Xia and Lee 2005, p. 54). *Helix Nebula* managers learned that complexity per se is not a problem *if* it is well balanced and harnessed, which was at first not achieved in *Helix Nebula*. In effect, *Helix Nebula*'s unbalanced complexity eventually culminated in partially failed cloud computing services, little platform scaling, and limited value *co*-creation. Neither explicit formal targets nor implicit individual organization's commercial targets were fully met. *Helix Nebula* has not scaled as initially targeted. *Helix Nebula* managers increasingly understood that digital platforms' unique *structure* (i.e., multiplicity, variety, and interdependency of elements), *dynamics* (i.e., varied rates and patterns of change over time), and *socio-technical* nature (i.e., organizational *and* IT elements) contribute to pervasive socio-technical complexity in digital ecosystems.

Against this backdrop, the case narrative of *Helix Nebula* is presented hereafter to serve digital platform analysts, designers, and managers as a consultable record. That is, this case description can be valuable for other organizations that may be motivated to implement a new (or improve a given) digital platform, but may not be aware of inherent complexity and related managerial countermeasures to cope with this complexity. I am hopeful that such organizations would benefit from reflecting on *Helix Nebula*'s experiences with socio-technical complexity, and consciously utilizing relevant actions taken and lessons learned as reported in this work.

Recognizing that it is impossible to capture all dimensions and characteristics of socio-technical complexity, this digital platform description seeks to make two contributions.[1] First, promising eight years of empirical evidence shed light on socio-technical complexity manifested in a revelatory digital platform. To this end, this work reports a classification framework that synthesizes and integrates four countermeasures against socio-technical complexity in digital platforms. Second, the case's narrative itself serves as consultable record of how socio-technical complexity manifests and consequently constrains the benefits of digital platforms. Thereby, this work addresses (i) *researchers* interested in digital platforms, digital ecosystems, socio-technical complexity, and cloud computing; and (ii) *practitioners* in organizations acting as platform owners, partners, clients, or subcontractors – all mutually seeking to establish a thriving digital *ecosystem* (Parker et al. 2017).

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[1] This study builds on a prior study (Huntgeburth et al. 2015), co-authored by the author of this work at hand. The prior study was presented and discussed at the 23rd European Conference on Information Systems. For the avoidance of doubt, after transparent communication with the previous co-authors, the author declares no conflicts of interest with respect to the idea, research, authorship, or publication of this article. Both studies draw on the same underlying single case study data, but they fundamentally differ in their topics of interest. While the prior study (Huntgeburth et al. 2015) uncovers *modes of value co-creation* predominantly for digital platform *researchers*, the article at hand reports *socio-technical complexity countermeasures* predominantly for digital platform *practitioners*. Consequently, due to different topics of interest, the study at hand differs in its conceptual foundation, coding scheme, data analysis, and results. Reused and adapted figures and tables are cited accordingly.

2. Situation faced

While few digital platforms thrive and grow, such as those of Alphabet (*Android*), *Amazon.com*, Apple (*iOS*), or Microsoft (*Windows*), most others fail to survive in the long run (Parker et al. 2017). A prominent example is Microsoft's *Windows Phone*. In 2013, Microsoft acquired Nokia's *Devices and Services* division in an attempt to leverage its extant mobile operating system. In 2017, Microsoft discontinued its support for *Windows Phone* (Briegleb 2017) with less than 0.2 per cent of all smart-phones running *Windows Phone* (Gartner 2017). *Helix Nebula* faced a similar destiny of platform failure in its three evolution phases: analysis phase (2011-2013), design phase (2014-2015), implementation phase (2016-today). Client and competition challenges in these phases impeded *Helix Nebula*'s growth.

Regarding **clients**, *Helix Nebula* faced a set of intricate client service requests, meeting each of which increased complexity. *Compute and Storage Services* support a range of virtual machines and container configurations working with datasets in the petabyte range. *Network Connectivity and Federated Identity Management Services* provide high-end network capacity for the whole platform with common identity and access management. *Payment Services* offer a range of purchasing options to determine and configure the most appropriate option for the scientific application workloads at hand to be deployed.

Regarding **competition**, prominent IT service providers, such as *Alphabet*, *Amazon Web Services*, *IBM*, *Microsoft*, *Oracle*, *Salesforce.com*, or *SAP*, had already started building up digital *ecosystems* by that time. These organizations act as orchestrators at the core of their digital ecosystem (Iansiti and Levien 2004; Ceccagnoli et al. 2012). Notably, *Alphabet*, *Amazon*, *Apple*, and *Microsoft* have become world's most valuable companies (Statista 2017). Each is marked by an extensible codebase to which complementary third-party modules can be added—a *digital platform* (Tiwana 2015; e.g., Parker et al. 2017; Reuver et al. 2017).

Consequently, (i) owing to pervasive evolution and adoption of cloud computing (client pressure); and (ii) owing to effectively compete with incumbents' omnipresent digital platforms (competitive pressure), *Helix Nebula* decided to also adopt the digital platform model. *Helix Nebula* thereby aimed to scale significantly beyond its extant three clients and to shift to a more dynamic process of value *co*-creation in a digital ecosystem (Ceccagnoli et al. 2012). This shift is seen as a "decisive factor in competition for tomorrow's distributed world of 'cloud computing'" (Williamson and De Meyer 2012, p. 32). It conforms to a shift in the economy toward service ecosystems (Vargo and Akaka 2012; Lusch and Nambisan 2015).

Helix Nebula's extended scale and scope of inter-organizational collaboration with a myriad of platform partners sparked different complexities:

- multiple, varied, and interdepend elements (*structural* complexity);
- organizational *and* technological elements (*socio-technical* complexity);
- varied rates and patterns of element changes over time (*dynamic* complexity).

Resulting high levels of socio-technical complexity constrained and risked the digital platform's benefits. Consequently, *Helix Nebula* faced a situation of complexity and uncertainty – both factual and perceived – that were found to be negative factors in IT-outsourcing and cloud-sourcing decisions (Schneider and Sunyaev 2014). Cloud computing customers "desire to receive a service which is simple to understand and use" (Venters and Whitley 2012, p. 180). Therefore, complexity emerged as *Helix Nebula*'s major concern in scaling its digital platform.

Helix Nebula managers lacked a thorough understanding of complexity in digital platforms. Since literature on digital platforms is scarce and its investigation from a *socio-technical complexity* perspective is lacking, digital platform managers do not find actionable advice on how to cope with complexity. Existing studies employ perspectives of *risk* (Hauff et al. 2014), *business models* (Leimeister et al. 2010), and *value co-creation* (Huntgeburth et al. 2015). Therefore, in line with Tilson et al.'s call for understanding and guiding "IT ecosystem dynamics" and "complex service ecologies" (2010, p. 757), *Helix Nebula* faced a situation of *how to reduce its socio-technical complexity to facilitate platform scaling, value co-creation, and platform permanence*.

3. Action taken

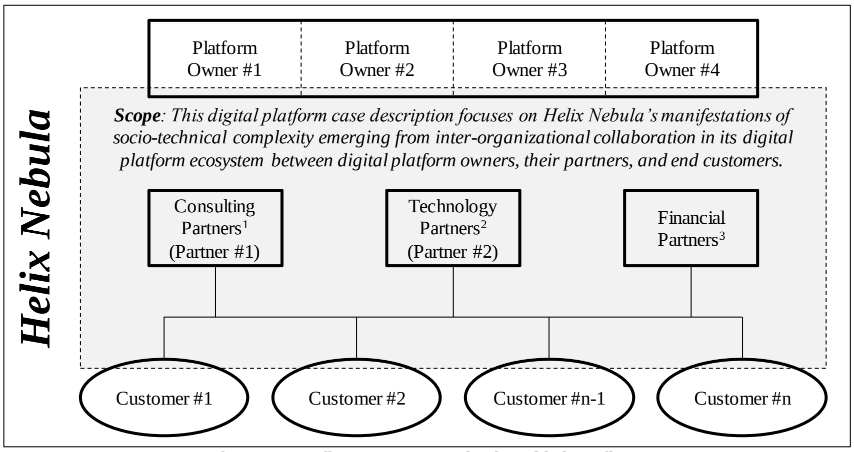
Helix Nebula opted for four consecutive and interrelated actions to reduce its pervasive socio-technical complexity. Table 1 synthesizes these actions. In what follows, each section specifies one of the taken actions.

Table 1. *Helix Nebula*'s Four-Stage Process in Reducing Socio-technical Complexity

Action	Input	Brief Description	Output
1. Ecosystem Analysis	Documentary evidence on *Helix Nebula*'s components	Conceptually modelling *Helix Nebula*'s ecosystem to shed light on undisclosed complexity amongst platform owners, partners, clients, and subcontractors	*Conceptual model* of *Helix Nebula*'s digital ecosystem
2. Complexity Definition	Complexity as identified root-cause of absent platform scaling	Agreeing upon a mutually shared understanding of socio-technical complexity	*Quadripartite framework* of socio-technical complexity (Xia and Lee 2005)
3. Complexity Evaluation	(1) Digital ecosystem model (2) Complexity framework	Interviewing representatives from platform owners, partners, clients, and subcontractors in the quest for unpacking the complexity construct in *Helix Nebula*	*Identified manifestations* of socio-technical complexity in *Helix Nebula*
4. Complexity Reduction	Manifestations of socio-technical complexity in *Helix Nebula*	Deriving and implementing countermeasures to reduce the identified manifestations of socio-technical complexity	Reduced socio-technical complexity; increased scaling of *Helix Nebula*

3.1 Action 1: Ecosystem Analysis

Two SAP employees seconded *Helix Nebula* as technology partners to analyze *Helix Nebula*'s digital ecosystem. They drew on fragmented documentary and verbal evidence on *Helix Nebula*'s architecture. This action aimed to shed light on undisclosed complexity amongst platform owners, partners, clients, and subcontractors. The resultant conceptual model of *Helix Nebula*'s digital ecosystem (see Figure 1) highlights a complex setup of *four* leading European public cloud Infrastructure-as-a-Service (IaaS) providers. They deliver IT services to client organizations in cooperation with platform partners and subcontractors over a shared digital platform. These organizations also operate a digital marketplace *HNX* to offer their cloud services. With *four* platform owners orchestrating *numerous* interdependent partners with different roles, a partner program focuses on helping licensed consulting, technology, and financial partners to build platform-based businesses by providing them with technical and marketing support. Moreover, *Helix Nebula* engages in a complex business model. That is, four federated IaaS providers mutually install a shared European digital platform based on distributed cloud computing technology and act as one integrated orchestrator to provide storage and processing capacities with a scale and complexity far beyond what can be provided by any single organization.



1 System Integrators, Consultancies, Resellers, Agencies, and Value-added resellers
2 Cloud Brokerage, Independent Software Vendors, SaaS, PaaS, Management and Security Vendors
3 Governments, Payment Services, Investors, and Financial Services

Figure 1. The Relationship between Infrastructure Providers, their Partners, and Customers (adapted from Huntgeburth et al. 2015)

3.2 Action 2: Complexity Definition

Drawing on an understanding that the complexity inherent in *Helix Nebula*'s architecture is *one* root-cause of absent platform scaling, the organizations started a four months lasting process of researching, discussing, defining, and agreeing upon a mutually shared understanding of socio-technical complexity. Specifically, Xia and Lee's (2005) conceptualization framework of information systems (IS) complexity[2] (see Figure 2) was and still is employed – covering both *organizational* and *technological* complexity (organizational vs. technological complexity) (i.e., socio-technical complexity). Moreover, it provides a *structural* (i.e., cross-sectional) and a *dynamic* (i.e., longitudinal) perspective on IS complexity (structural vs. dynamic complexity). Through the combination of these views on complexity, Xia and Lee outline four components of IS complexity: *Structural organizational* complexity describes the multiplicity and interdependency of organizational elements (e.g., end users, project team, management, or external contractors/vendors). *Structural IT* complexity describes the multiplicity and interdependency of technological elements (e.g., technology platform, software environments, or data processing requirements). *Dynamic organizational* complexity describes the rate and pattern of changes in organizational environments (e.g., changes in user information needs, business processes, and organizational structures). *Dynamic IT* complexity describes the rate and pattern of changes in the IT environment (e.g., changes in infrastructure, architecture, and development tools).

Organizational	Structural Organizational Complexity (SORG)	Dynamic Organizational Complexity (DORG)
Technological	Structural IT Complexity (SIT)	Dynamic IT Complexity (DIT)
	Structural	Dynamic

Figure 2. Constituents of Socio-technical Complexity (Xia and Lee 2005)

3.3 *Action 3: Complexity Evaluation*

Drawing on both (i) the conceptual model of *Helix Nebula*'s digital ecosystem (see *Action 1*) and (ii) the framework of socio-technical complexity (Xia and Lee 2005) (see *Action 2*), two *Helix Nebula*-affiliated analysts intensively collected data from April 2013 to February 2014. These analysts are SAP employees, a *Helix Nebula* technology partner at that time. Specifically, they documented manifestations of complexity in *Helix Nebula* in semi-structured interviews, pilot studies, strategy workshops, weekly alignment meetings with all partners, informal bilateral calls with platform partners, and other documentary evidence. Specifically, ten semi-

[2] From a scientific perspective, Helix Nebula's action two combines *socio-technical theory* (Bostrom and Heinen 1977a, b) and *complexity theory* in organization science (Anderson 1999) to explore manifestations of socio-technical complexity in the context of digital platform ecosystems. The resultant *socio-technical approach* emphasizes joint optimization of social and technical subsystems to maximize performance of an overall organizational system (e.g., a digital platform ecosystem) by recognizing the interdependency of the social and technical subsystems.

structured interviews were conducted in November and December 2013 including representatives from platform owners, partners, clients, and subcontractors. The SAP analysts ensured that interviewees have cloud computing and digital platform knowledge. *Helix Nebula*'s complexity evaluation efforts ensure a *quadripartite* perspective on digital platforms (owner, partners, end user organizations, subcontractors). Table 2 underscores the four different perspectives. This *multi*-perspective approach has proofed particularly valuable in evaluating socio-technical complexity of digital platforms. For instance, what *one* organization (e.g., a platform owner) perceives as value-adding complexity, *another* organization (e.g., a technology partner) perceives as value-destroying complexity. Since the data covers socio-technical complexity well, it presents an enormously rich source for unpacking the complexity construct in ecosystems.

Table 2. Organizations and Profiles of the Interviewees (Huntgeburth et al. 2015)

Organization	Brief Description	Position/Role
Client #1	European intergovernmental big science (2 250 employees) Research in space and earth surface exploration	Satellite Mission Manager (C1_M)
Client #2	European intergovernmental big science (1 900 employees) Research in life science	Head of IT Services (C2_M)
Owner #1	Multinational IT services corporation (78 000 employees) Solid track record in developing and delivering cloud services Leads the cloud platform and provisioning in *Helix Nebula*	Principal Solutions Architect (O1_M)
Owner #2	Pure public IaaS provider (40 employees) Enterprise-class cloud servers and cloud hosting solutions Leads the user and service requirements in *Helix Nebula*	Manager Enterprise Solutions Architecture (O2_M)
Partner #1	Multinational IT services corporation (100 000 employees) IT infrastructure and managed services experience Leads the flagship deployment as technology partner for IT infrastructure brokerage in *Helix Nebula*	Solutions Architect (P1_M)
Partner #2	Cloud and distributed system solution provider (20 employees) Specialized in agile delivery and process automation Leads the technical architecture track in *Helix Nebula*	Co-Founder (P2_M)
External #1	Multinational software and IT services corporation (2 600 employees) Cloud-based applications with the largest web-based trading ecosystem	Vice President of Business Network Strategy (E1_M)
External #2	Multinational enterprise software corporation (8 000 employees) Industry's only in-memory cloud platform ecosystem	Senior Director of Global Business Development (E2_M)
External #3	Multinational management consulting (425 500 employees) Technology services and outsourcing professional service provider Worldwide leading consulting experience in cloud service integration	Platform ecosystem Alliance Channel Director (E3_M#1) Lead Architect of Agile IT (E3_M#2)

3.4 Action 4: Complexity Reduction

Drawing on the complexity evaluation (see *Action 3*), the platform owners implemented countermeasures in four categories: *orchestration*, *standardization*, *autonomization*, and *modularization*. These countermeasures have been implemented to reduce the identified manifestations of socio-technical complexity. Table 3 presents a classification framework to synthesize the four categories of employed countermeasures – serving *Helix Nebula* as an organizing, simplifying, and steering framework to (1) classify its manifestations of complexity and (2) reduce them through according countermeasures. The framework's contextual, empirical understanding in the case of *Helix Nebula* as well as the generalized four categories of countermeasures against socio-technical complexity are presented hereafter.

Table 3. A Classification Framework of Countermeasures against Socio-technical Complexity in Digital Platforms

Type	Structural Organizational (SORG) Complexity	Structural IT (SIT) Complexity	Dynamic Organizational (DORG) Complexity	Dynamic IT (DIT) Complexity
Challenge	Multiplicity, variety, and interdependency of actors and relations in digital ecosystems	Multiplicity, variety, and interdependency of IT in digital ecosystems	Varied rates and patterns of *organizational* changes in actors and relations in digital ecosystems	Varied rates and patterns of *technological* changes in actors and relations in digital ecosystems
Action	**Orchestration**	**Standardization**	**Autonomization**	**Modularization**
Result	Organizational integrity	Technological integrity	Organizational generativity	Technological generativity
Mechanism	(1) *Central organizational* actions undertaken by the digital platform owner(s) (2) in response to the multiplicity, variety, and interdependency of actors and relations (3) to control the digital ecosystem's organizational integrity; and to extract value from the ecosystem for the platform owner(s), partners, and clients.	(1) *Central technological* actions undertaken by the digital platform owner(s) (2) in response to the multiplicity, variety, and interdependency of existing IT arrangements (3) to stabilize the technological integrity of the ecosystem; and to capitalize on resource diversities for digital service innovation.	(1) *Decentral organizational* actions undertaken by distributed, loosely coupled actors (2) in response to environmental stimuli and competitive pressures causing varied rates and patterns of *organizational* change in the ecosystem (3) to (re)configure organizational structures to align actors in different ways.	(1) *Decentral technological* actions undertaken by distributed, loosely coupled actors (2) in response to environmental stimuli and competitive pressures causing varied rates and patterns of *technological* changes the ecosystem (3) to synergistically co-create value in arbitrary n-lateral ways to suit varied innovation opportunities
Techniques	• Resolving coopetition tensions • Control mechanisms for maintaining/ increasing ecosystem stability • Designing macro logic of network structure • Managing micro logic of network processes	• Supplementary IT resource integration • Complementary IT resource integration	• *Business/ contractual flexibility* for customers and partners • Leakage/ exploitation of proprietary knowledge • Self-reinforcing, informal mechanisms • Formal and more warily mechanisms	• Context-specific, dynamic resource integration for value co-creation in ecosystems • *Functional/ technical flexibility* demanding scalability, interoperability and modularity
Implication	The greater the multiplicity, variety, and interdependency of actors, the greater the need of orchestrating the digital ecosystem.	The greater the multiplicity, variety, and interdependency of IT, the greater the need of standardizing the digital ecosystem.	The more varied the rates and patterns of organizational change in actors, the greater the need of autonomizing the digital ecosystem.	The more varied the rates and patterns of technological change in actors, the greater the need of modularizing the digital ecosystem.

Orchestration. Selected empirical evidence highlights the results of *Helix Nebula*'s evaluation of structural organizational complexity (see *Action 3*). This type of complexity refers to the multiplicity, variety, and interdependency of actors and relations in *Helix Nebula*.

*"It is also contractually and process wise an orchestration challenge. [...] Helix Nebula is not one commercial or one organization [sic!] entity that we can talk to [...] and that we can receive bills from or that we can contract. It is rather an aggregation of different partner organizations under one umbrella and operated by one operator organization. [...] following individual terms and conditions [...] is another level of **complexity** in terms of orchestrating all these things together." (C2_M)*

*"It is both. [...] So it is not only the **complexity of requirements** that are posed by the user side but also the **complexity** by introducing difference from completely different vendors and aggregating them under one umbrella. That is a challenge in the complexity from both sides." (C2_M)*

*"[...] the complexity comes because the service is then being offered by so many organizations. So we have P1 offering the EC2 Bridge. We have F2 who are hosting the blue box which is being offered by P2. Also the service support is then being offered by P3. And then also there is a web portal, which is being offered by F3. [...] **complexity** comes because there are so many organizations involved." (P1_M)*

Helix Nebula platform owners increasingly orchestrate their digital ecosystem through central control. Thereby, they reduce the outlined manifestations of structural organizational complexity and increase their ecosystem's organizational integrity. Its foundational mechanism is that top-down, regulative control through central governance by the orchestrators facilitates organizational integrity. Orchestration is required due to the multiplicity, variety, and interdependency of actors in *Helix Nebula*. One or more hub firm(s) and a myriad of loosely coupled partners collaborate in digital ecosystems. These partners vary in their roles – technology, consulting, regulation, or financial partners (see Figure 1). For all actors to collaborate efficiently and effectively, a set of central organizational actions (*orchestration*) is required to control the ecosystem's organizational integrity (Lusch and Nambisan 2015).

Standardization. Selected empirical evidence highlights the results of *Helix Nebula*'s evaluation of structural IT complexity (see *Action 3*). This type of complexity refers to the multiplicity, variety, and interdependency of *Helix Nebula*'s IT.

*"We need to find a way for Oracle and MySQL and MSSQL and Mongo and Apache and all of these other different data providers to work together. It is possible, but very complex. There are technologies that exist in the world that are prepared to sit above multiple sources of data and to provide a global catalogue and a global access methodology to that data; but this is a **very, very complex piece of infrastructure**." (O2_M)*

*"It introduces **complexity** as the individual vendors not all have the same underlying infrastructure. So compared to the big global players who have [...] just one infrastructure or only few infrastructures to cater for, in Helix Nebula [...] that is different. [...] Building the blue box [a brokerage tool] and seeing that there are*

some different levels of complexity from the different vendors that offer cloud computing resources […] is certainly a challenging piece of work." (C2_M)

Helix Nebula platform owners increasingly standardize their ecosystem's IT through central control. Thereby, they reduce the outlined manifestations of structural IT complexity and increase the ecosystems technological integrity. The platform owners impose top-down, regulative standardization of extant IT arrangements. Its foundational mechanism is that standardization facilitates technological integrity. A digital ecosystem's actors inherently contribute unique IT resources. For all actors to collaborate efficiently and effectively, *Helix Nebula* now operates a set of central technological actions to facilitate technological integrity (Lusch and Nambisan 2015).

Autonomization. Selected empirical evidence highlights the results of *Helix Nebula*'s evaluation of dynamic organizational complexity (see *Action 3*). This type of complexity refers to the varied rates and patterns of organizational changes in actors and relations in *Helix Nebula*.

"*One of them is the* ***complexity of data ownership*** *and intellectual property and so on. […] Whose information is it? Whose data is it? Who is paying for it? People have these ideas that selling the information will pay for the storage of the data which ultimately it might do. But we are a long way from that […]." (F1_M)*

"These [customer] organizations have a complex procurement process which means they have to consider things such as geo return, so that the countries which fund these organizations get back a fair share of work. […] then there are ***all these kinds of complex rules*** *that then determine how they can procure things. So in Helix Nebula we are coming up with a complex approach, which will allow them to procure things which then align with those rules." (P1_M)*

Helix Nebula platform owners increase their digital ecosystem's generativity through granting partners, clients, and subcontractors decentral and local autonomy only in *certain* decisions. That is, it has gained the "capacity of a self-contained (digital) system to generate new outputs, structures, or behaviors endogenously through the participation of uncoordinated third-party actors without deliberate planning from the originator of the system" (Lyytinen et al. 2016, p. 7). Thereby, they control the outlined manifestations of dynamic organizational complexity and increase the ecosystem's organizational generativity. The platform owners grant certain degrees of freedom to foster decentral, local bottom-up emergence, commonly referred to as generativity. Digital ecosystems comprise a diverse set of loosely coupled actors that are relatively free to enter and exit the ecosystem and form different n-lateral configurations with other actors for the delivery of a specific IT service to serve a given client's needs. To this end, a fair degree of actor agency is required to provide for organizational generativity (Lusch and Nambisan 2015) in digital ecosystems.

Modularization. Selected empirical evidence highlights the results of *Helix Nebula*'s evaluation of dynamic IT complexity (see *Action 3*). This type of complexity refers to the varied rates and patterns of technological changes in actors and relations in *Helix Nebula*.

"[The partners] have to find a way of matching what the customer requirements are, the particular unique set of resources to a range of possible provisions and do so in a structured and reasonably deterministic way. [...] That is not as simple as it may sound. [...] we know that aligning resources is a ***complex*** *process." (F1_M)*

"The other aspects are [...] technology. Its [IaaS] needs certainly offer much more flexibility than one individual organization can leverage and handle. Flexibility is key. It will be key to have elasticity of individual infrastructures. It will be ***much more complex*** *than the ones [...] provided by individual resources." (C2_M)*

"So there is complexity there around the ***large amount of data*** *which we are going to be storing. [...] Then around the description of what data is available and how that data is stored and how you interface with that data; it is unlikely that we will ever see one common approach to that" (P1_M)*

Helix Nebula platform owners increasingly modularize the ecosystem through decentral autonomy. Thereby, they reduce the outlined manifestations of dynamic IT complexity and increase the ecosystems technological elasticity. Thus, the digital platform's modular IT architecture balances top-down, central control and bottom-up, and decentral emergence. Modularity refers to the separation and recombination of infrastructure components. Its foundational mechanism is that a modular architecture facilitates a digital ecosystem's technological generativity. Actors can trigger IT changes within their organizations and across the network due to a fair degree of agency (Lusch and Nambisan 2015). For this reason, *Helix Nebula* has ensured to become more generative.

4. Results achieved

Helix Nebula's four-stage process in reducing socio-technical complexity (see Section 3) contributed to improvements in three areas. First and foremost, after the countermeasures' implementation in 2014, socio-technical complexity has decreased to a value-adding level, while *Helix Nebula* has scaled more successfully.

4.1 Result 1: Increased Platform Scaling

Since its creation in 2011, *Helix Nebula* has overcome its complexity challenges and grown to become a leading public-private partnership between public research organizations and cloud service providers. The outlined countermeasures resulted in a new governance structure entitled *HNSciCloud*. In 2017, the initiative has undertaken its first joint pre-commercial procurement (PCP) tender called *HNSciCloud* to support the deployment of high-performance computing and big-data capabilities for scientific research. This €5.3 million PCP tender is sponsored by ten of Europe's leading public research organizations (CERN, CNRS, DESY, EMBL-EBI, ESRF, IFAE, INFN, KIT, STFC, SURFSara) and co-funded by the

European Commission. Beyond, a wider range of organizations has shown interest in participating in the procurement group.

The streamlined governance structure *HNSciCloud* simplifies the multiplicity, variety, and interdependency of actors and IT as well as the varied rates and patterns of organizational and technological changes in *Helix Nebula*'s digital ecosystem. *HNSciCloud* refers to a procurement of innovative IaaS solutions before they are commercially available (see Figure 3). In November 2016, four consortia won the *HNSciCloud* PCP tender for further implementing *Helix Nebula*. This clarification of actors and relations has reduced complexity significantly. *HNSciCloud* involves the current 40 platform owners, partners, and clients that all compete through different phases of development. The risks and benefits are shared between the platform owners, partners, and clients under market conditions. For PCPs, risk-benefit sharing under market conditions is when platform clients share the benefits and risks with platform owners and partners at market prices. R&D is split into phases (exploration, design, prototyping, pilot) with the number of competing R&D providers being reduced after each evaluation phase.

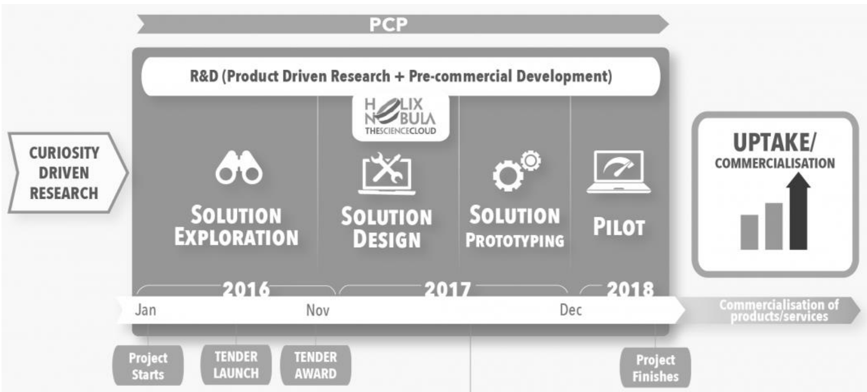


Figure 3. *Helix Nebula*'s Simplified Governance Structure *HNSciCloud*

4.2 Result 2: Increased Value Co-creation

Reducing its socio-technical complexity has allowed *Helix Nebula* to more effectively *co*-create value in three areas (Huntgeburth et al. 2015). First, the federated four platform owners started bartering and pooling IT infrastructure resources (i.e., networking, storage, servers, visualization, processing). This effort co-creates the value of higher scale and elasticity of the digital platform and reduces cloud vendor lock-in due to the choice between four IT infrastructure providers. Peak demands by one IT infrastructure provider request higher scale and elasticity of the digital platform. This effect can be mitigated due to an hourly compensated exchange on an internal *Helix Nebula* storage and capacity market. Further, inter-organizational, technological standards reduce cloud vendor lock-in. This is illustrated as follows.

"The requirements of the existing demand side could not be handled solely by one of the providers […]. By working together, we are able to build toward a scale which […] no single cloud provider can offer. […] We are able to offer large amounts of cloud computing resources." (P1_M)

Second, consulting and technology partners layered additional services on *HNX*, *Helix Nebula*'s self-service marketplace. These partners thereby gain global reach and signal effects through collaboration with the platform providers. This effort co-creates the value of the existence of a European-wide integrated, trusted cloud computing marketplace. This marketplace allows for hybrid and multi-cloud deployment scenarios appropriate to clients' existing business processes and in-house IT. The marketplace provides clients with a larger service pool including especially hybrid and multi-cloud deployment scenarios. This is illustrated as follows.

"What we end up with is in essence a marketplace where cloud vendors – again a small chosen group to begin with, but eventually a larger group of cloud vendors – will be able to come and offer their […] services in a way that will be understandable to the potential user community and will be governed by a set of service and business and technology rules." (F2_M)

Third, reduced complexity allows platform clients to amalgamate IT infrastructure, data, and software resources. This amalgamation of resources co-creates the value of integrated, customized new information services. For instance, clients are enabled to manage the risks posed by ground deformations. Furthermore, the synergistic integration of cloud firms yields in cross-fertilization and analysis of big data in heterogeneous formats. This is illustrated as follows.

"It is complementation and aggregation of data and information from public, quite unrelated resources, and [Helix Nebula] pools and puts that together and arrives at new opportunities and new insights. […] That is one. If we focus on the future and why we would see information as a service being important, then that was one driver. The other driver was partly also kind of an outsourcing argument that we could use external capacities in order to facilitate providing IT sources in times of peaks or in times of very fast deployment […]." (C2_M)

4.3 Result 3: Capabilities for Digital Platform Permanence

In the process of reducing its socio-technical complexity, *Helix Nebula* developed four capabilities to permanently ensure its digital platform survival. Capability refers to the ability to repeatedly perform or achieve certain actions or outcomes which relate either directly or indirectly to a firm's capacity for creating value (Grant 1999). For instance, a hospital's capability in cardiovascular surgery is dependent on integrating the specialist knowledge of surgeons, anesthetist, radiologist, operating-room nurses, and several types of technicians. With the same token, *Helix Nebula*'s capability in leveraging digital platform permanence is dependent on integrating the owner's, partners', clients', and further stakeholders' resources.

Orchestration. Maintaining organizational integrity in the ecosystem is an orchestrator's central capability (Lusch and Nambisan 2015). First, the orchestrator needs to balance the tension between simultaneous cooperation and competition across different types of organizational roles and resources over time mitigating the tensions caused by *coopetition* (Ritala 2012). Second, the orchestrator needs to manage the strategy, architecture, co-learning, value co-creation/ capture, and processes. For instance, certifying the reliability of interrelated IT service providers is a complex endeavor (Schneider and Sunyaev 2015). In fact, the removal of the orchestrator(s) will in many cases result in a collapse of the ecosystem (Iansiti and Levien 2004). Third, digital platform ecosystem orchestration demands to simultaneously focus both on the macro logic of network structure and the micro logic of network processes (Venkatraman and Chi-Hyon Lee 2004). The orchestrator needs to *design* the macro logic of network structure by recruiting and aligning further partners (membership, structure, and market position). Conversely, the orchestrator needs to *manage* the micro logic of network processes that facilitate value co-creation (knowledge mobility, innovation appropriability, and network stability) (Dhanaraj and Parkhe 2006).

Standardization. *Helix Nebula* managers have developed the capability of integrating supplementary and complementary resources by means of effective standardization. First, *supplementary* resource alignment refers to pooling similar kinds of resources – that is, homogeneous or horizontal ecosystem (Lavie 2006; Han et al. 2012). Platform owners intend greater scale, enhanced competitive position, economic efficiency, and strategic, organizational, and operational compatibility in their industry (Das and Teng 2000). Within *Helix Nebula*, the four IaaS providers (e.g., Focal #1, Focal #2) federate, barter, and exchange storage, processing, and network resources to build a common digital infrastructure (Tilson et al. 2010). The scale, interdependency, and complexity of that digital infrastructure reaches far beyond what any single platform owner could provide on its own. Second, *complementary* resource alignment refers to integrating resources with diminutive intersections – that is, inhomogeneous or vertical ecosystem (Lavie 2006; Han et al. 2012). Organizations seek to access resources that are otherwise hard to obtain (Hill and Hellriegel 1994). Within *Helix Nebula*, organizations synergistically integrate digital infrastructure, data, and software resources. IaaS providers cross-fertilize and exploit data hosted by customer’s (e.g., Customer #1, Customer #2) with the help of the technology partners for data analysis to provide integrated, customized new IT-enabled information services.

Autonomization. *Helix Nebula* managers have learned how the digital platform best adapts “to new environmental stimuli and competitive pressures and, in turn, create new service innovation opportunities” (Lusch and Nambisan 2015, p. 164). Decentral organizational changes require business/ contractual flexibility (Benlian et al. 2011) covering the degrees of freedom that actors have in changing actor-generated institutions and institutional arrangements (Vargo and Lusch 2016). Specifically, *Helix Nebula* needs to take care of complex open and restricted tender rules that determine how the customer can procure IT resources. Further, the dynamic, context-specific aggregation, mining, and analysis of interfirm information sources raises complex security and privacy considerations. On the one hand, self-reinforcing, informal mechanisms of coevolving trust, goodwill, and commitment are required. On the other hand, reality often demands formal and more warily isolation mechanisms such as patents, trademarks, or contracts to protect strategic resources (Lavie 2006).

Modularization. Ultimately, *Helix Nebula* managers have learned how to design the platform more flexible. *Functional/ technical flexibility* refers to scalability, interoperability, and modularity (Benlian et al. 2011). Scalability depends on the time in which resources can be (de-)allocated as required and the maximal number of simultaneously available resources (e.g., user accounts, instances, functions, or services). Interoperability describes the integration degree between services of the same provider and services of different providers. In *Helix Nebula*, customers' capacity requirements vary that much in terms of scale of requested IT resources that *Helix Nebula* needed to establish an internal storage and capacity market to reach a better scale and elasticity of the platform. Further, *Helix Nebula* clients' requests for information and data services are unpredictable. This requires an adaptability of infrastructures, tools, and data sets in capturing, processing, analyzing, and archiving heterogeneous data.

5. Lessons learned

Helix Nebula managers learnt how to reduce socio-technical complexity manifested in their digital ecosystem in the quest for increased platform scaling, value *co*-creation, and permanence of their digital platform. The outlined digital platform case *Helix Nebula* was reported from a socio-technical complexity perspective. Specifically, the conceptualization of socio-technical complexity by Xia and Lee (2005) was applied. Reflecting the overall digital platform case, *Helix Nebula* analysts, designers, and managers have learnt the following lessons.

Lesson #1: Simplified governance structures reduce the socio-technical complexity of digital platforms. In 2016, *Helix Nebula* started its implementation phase. To this end, it employed a simplified governance structure denoted *HNSciCloud* (see *Section 4.1* and *Figure 3*). This structure contributed to simplifying the multiplicity, variety, and interdependency of platform-affiliated actors and IT as well as the varied rates and patterns of changes in *Helix Nebula*'s digital ecosystem. This governance structure has considered the performance, security, and management aspects of a hybrid cloud platform, including technical standards, interoperability, portability, as well as building trust and confidence in cloud computing services – all in the context of large public research organizations.

Lesson #2: An early adopter program reduces perceived complexity and insecurity for platform clients. In its design phase (2014-2015), *Helix Nebula*'s beta version suffered from a lack of early adopters. Early adopters are crucial for reaching a digital platform's critical mass of both platform partners and platform clients (Parker et al. 2017). *Helix Nebula*'s complexity reduction efforts unveiled that interested organizations perceived the platform as too complex and uncertain. To this, *Helix Nebula* installed an early adopter program for research organizations. This program offers a legal framework and access conditions to make the adoption of the digital platform as simple as possible. For instance, interested research organizations can fund the use of *Helix Nebula* services via their regional, national, or European commission projects. This made the purchase of the cloud services way simpler. Early adopter group members benefit from evaluating the use of commercially supported cloud services that were selected and tested against a range of use-cases that are directly relevant for the research community.

Lesson #3: Succinct statements serve as guiding principles in reducing socio-technical complexity in digital platforms. *Helix Nebula* managers have translated their experiences and learnings in reducing socio-technical complexity in digital platforms to succinct principles. Each implication covers one of the four constituents of socio-technical complexity in digital platforms. They serve as starting point to quantify and manage an otherwise hard-to-grasp management problem: digital platform complexity. While two guiding principles (*orchestration* and *standardization*) reflect the need of maintaining organizational and technological integrity, the other two (*autonomization* and *modularization*) reflect the need of maintaining organizational and technological generativity in digital ecosystems.

1. **Orchestration:** The greater the multiplicity, variety, and interdependency of actors, the greater the need of orchestrating the digital ecosystem.
2. **Standardization:** The greater the multiplicity, variety, and interdependency of IT, the greater the need of standardizing the digital ecosystem.
3. **Autonomization:** The more varied the rates and patterns of organizational change in actors, the greater the need of autonomizing the digital ecosystem.
4. **Flexibilization:** The more varied the rates and patterns of technological change in actors, the greater the need of modularizing the digital ecosystem.

Lesson #4: Accessing socio-technical complexity is highly challenging. *Helix Nebula* faced “the huge challenges in studying large-scale complex phenomena” (Tilson et al. 2010, p. 751), such as its digital ecosystem. These challenges constrain the exploration and understanding of the dimensions and characteristics of socio-technical complexity that are important and relevant for management – and therefore should be captured by a classification framework like the one presented in this case description. Moreover, these challenges in studying socio-technical complexity constrain the understanding of which complexity characteristics are beneficial and which are constraining. Against this backdrop, *Helix Nebula* managers soon learnt that interpreting and applying the complexity constituents reported here should be done cautiously. While *Helix Nebula*’s systematic complexity evaluation (see *Action 3*) guided by a theoretical framework reflects the most critical aspects of socio-technical complexity (Xia and Lee 2005), *Helix Nebula*’s complexity evaluation showed the huge challenges of studying large-scale complex phenomena. By drawing on a *single European-based* case study which was *not* analyzed over its entire life-cycle – much rather its design and implementation phases –, parts of the understanding of socio-technical complexity can be refined in their generalizability. Moreover, given the customer’s importance in digital ecosystems, the customer facet in the complexity construct and how customers may contribute to complexity in ecosystems is considered too implicitly. Overall, the lesson to be learnt is that it is impossible to capture all dimensions and characteristics of complexity.

Lesson #5: Reducing socio-technical complexity requires parsimonious and succinct approaches. While studying and limiting socio-technical complexity in digital ecosystems involves huge challenges due to the scale and scope of complex phenomena (see *Lesson #4*), *Helix Nebula* learnt that to effectively communicate and limit its socio-technical complexity, it needed to identify a parsimonious and succinct conceptualization of its socio-technical complexity. This is because more sophisticated classification frameworks than the one presented turned out to be hard to understand and neither mutually exclusive nor collectively exhaustive. As such, other attempts of framing *Helix Nebula*'s socio-technical complexity raised more questions among employees than they answered. Owing to this learning – that is, a parsimonious and succinct classification framework is more effective –, four constituents of socio-technical complexity along with their second-order theoretical understanding (Lee 1991; Walsham 2006) emerged from *Helix Nebula*'s complexity reduction efforts (see Section 3). While two constituents (i.e., *orchestration* and *standardization*) reflect the complexity of maintaining organizational and technological integrity, the other two constituents (i.e., *autonomization* and *modularization*) reflect the complexity of maintaining organizational and technological elasticity in digital platform ecosystems. Each constituent comprises a succinct managerial proposition that captures *Helix Nebula*'s learning regarding the constituent. Overall, the lesson to be learnt is that effective communication and management of complexity demands parsimonious and succinct approaches.

Lesson #6: A complexity sweet spot balances required and unrequired socio-technical complexity. While *Helix Nebula*'s complexity analysis started under the naïve premise that complexity is *always* bad, *Helix Nebula* learnt that complexity can be advantageous for a digital platform ecosystem's success. As such, complexity in digital platform ecosystems can pose both *good effects* (enabling, rewarding, value-adding, required, and, desirable) and *bad effects* (constraining, unrewarding, value-destroying, unrequired, and undesirable). Notably, complexity is of different kind in digital platform ecosystems than in IS development projects.

Specifically, regarding *good effects*, socio-technical complexity turned out to be advantageous through the exchange, addition, and synergistic integration of distributed and heterogeneous resources. Competitive advantages far beyond what any single organizations can achieve on its own resulted. In *Helix Nebula*, multiple IT infrastructure providers federate, barter, and pool IT infrastructure to build an integrated, standardized digital infrastructure facilitating value co-creation. Beyond, multiple officially licensed technology and consulting partners add further layers of IT skills, resources, and experiences on the digital infrastructure to build a digital platform marketplace. Ultimately, multiple complementary resource integrators amalgamate infrastructure, data, and software resources in a mutually reinforcing manner to design computing and information services.

Conversely, regarding *bad effects*, socio-technical complexity turned out to be disadvantageous through organizing the exchange, addition, and synergistic resource integration of resources unnecessarily complex. Specifically, decreasing infrastructural connectivity inhibited resource mobilization and demobilized platform partners. Thus, less computing and information services were available on the online marketplace *HNX*. Beyond, *Helix Nebula*'s reach decreased as existing and prospective partners' marketplace modules deteriorated due to unbalanced complexity. Ultimately, less users adopted the *Helix Nebula* platform as less resources were invested. This decreased the usefulness of the platform ecosystem. Overall, the lesson to be learnt is that future research and management approaches should carefully differentiate between *good* and *bad* complexity. Potentially, future approaches find ways to even identify a complexity sweet spot. Multiple case studies could validate, refine, and enhance the proposed constituents.

Lesson #7: An ambidexterity sweet spot balances structural integrity and structural elasticity. Digital platform design needs to enable associated digital platform ecosystems to become ambidextrous. That is, digital platform ecosystems require a balance between (i) top-down, central *control* through the platform owners' *orchestration* and *standardization*; and (ii) bottom-up, decentral *emergence* through partners' *autonomization* and *modularization*. In that respect, if structural complexity remains uncontrolled and goes beyond certain limits, it will significantly constrain the elasticity of digital platform ecosystems. Reversely, if dynamic complexity remains uncontrolled and goes beyond certain limits, the structure of the digital platform ecosystem will diverge. Thus, while digital platform owners should exert (i) top-down, central *control* (to account for structural complexity and to maintain structural integrity), digital platform owners should allow for (ii) bottom-up, decentral *emergence* (to account for dynamic complexity and to main structural elasticity). Overall, the lesson to be learnt here is that digital platform owners should allow for both control and stability as well as for autonomy and change.

Lesson #8: Helix Nebula's case narrative serves as consultable record. Finally, to conclude, the case narrative of *Helix Nebula* itself is an important learning for researchers and practitioners, serving as a consultable record. The case highlights socio-technical complexity of an exemplary digital platform ecosystem with four federated IT organizations orchestrating an extended, dynamic actor-to-actor network. Reflecting this model can be valuable for other organizations that may be motivated to implement a digital platform ecosystem but may not be aware of inherent socio-technical complexity and managerial actions to cope with it. The author is hopeful that such organizations would benefit from reflecting on *Helix Nebula*'s experiences with socio-technical complexity, and consciously utilizing relevant conceptual knowledge embedded in this work.

References

Anderson P (1999) Perspective: Complexity theory and organization science. Organ Sci 10:216–232

Benlian A, Koufaris M, Hess T (2011) Service Quality in Software-as-a-Service: Developing the SaaS-Qual Measure and Examining Its Role in Usage Continuance. J Manag Inf Syst 28:85–126

Bostrom RP, Heinen JS (1977a) MIS Problems and Failures: A Socio-Technical Perspective PART I: THE CAUSES. MIS Q 1:17–32

Bostrom RP, Heinen JS (1977b) MIS Problems and Failures: A Socio-Technical Perspective PART II: The Application of Socio-Technical Theory. MIS Q 1:11–28

Briegleb V (2017) End of Life: Windows Phone ist offiziell tot. In: Heise Online. https://www.heise.de/ho/meldung/End-of-Life-Windows-Phone-ist-offiziell-tot-3769434.html. Accessed 24 Nov 2017

Ceccagnoli M, Forman C, Huang P, Wu D j. (2012) Cocreation of Value in a Platform Ecosystem: The Case of Enterprise Software. MIS Q 36:263–290

Das TK, Teng B-S (2000) A Resource-Based Theory of Strategic Alliances. J Manag 26:31–62

Dhanaraj C, Parkhe A (2006) Orchestrating Innovation Networks. Acad Manage Rev 31:659–669. doi: 10.5465/AMR.2006.21318923

Gartner (2017) Gartner Says Worldwide Sales of Smartphones Grew 9 Percent in First Quarter of 2017. https://www.gartner.com/newsroom/id/3725117. Accessed 24 Nov 2017

Grant RM (1999) Prospering in dynamically-competitive environments: Organizational capability as knowledge integration. In: Knowledge and strategy. Elsevier, pp 133–153

Han K, Oh W, Im KS, et al (2012) Value Cocreation and Wealth Spillover in Open Innovation Alliances. MIS Q 36:291–316

Hanseth O, Lyytinen K (2010) Design theory for dynamic complexity in information infrastructures: the case of building internet. J Inf Technol 25:1–19

Hauff S, Huntgeburth J, Veit D (2014) Exploring uncertainties in a marketplace for cloud computing: a revelatory case study. J Bus Econ 84:441–468. doi: 10.1007/s11573-014-0719-3

Hill RC, Hellriegel D (1994) Critical Contingencies in Joint Venture Management: Some Lessons from Managers. Organ Sci 5:594–607. doi: 10.1287/orsc.5.4.594

Huntgeburth J, Blaschke M, Hauff S (2015) Exploring Value Co-creation in Cloud Computing Platform Ecosystems: A Revelatory Case Study. In: Proceedings of the Twenty-Third European Conference on Information Systems (ECIS). Münster, Germany

Iansiti M, Levien R (2004) The Keystone Advantage: What the New Dynamics of Business Ecosystems Mean for Strategy, Innovation, and Sustainability. Harvard Business Press, Massachusetts, Boston

Lavie D (2006) The Competitive Advantage of Interconnected Firms: An Extension of the Resource-Based View. Acad Manage Rev 31:638–658. doi: 10.5465/AMR.2006.21318922

Lee AS (1991) Integrating Positivist and Interpretive Approaches to Organizational Research. Organ Sci 2:342–365. doi: 10.1287/orsc.2.4.342

Leimeister S, Böhm M, Riedl C, Krcmar H (2010) The Business Perspective of Cloud Computing: Actors, Roles and Value Networks. In: Proceedings of the 18th European Conference on Information Systems. Pretoria, South Africa

Lusch RF, Nambisan S (2015) Service Innovation: A Service-dominant Logic Perspective. MIS Q 39:155–175

Lyytinen K, Yoo Y, Boland Jr RJ (2016) Digital product innovation within four classes of innovation networks. Inf Syst J 26:47–75

Parker G, Van Alstyne M, Jiang X (2017) Platform Ecosystems: How Developers Invert the Firm. MIS Q 41:255-A4

Reuver M de, Sørensen C, Basole RC (2017) The Digital Platform: A Research Agenda. J Inf Technol 1–12. doi: 10.1057/s41265-016-0033-3

Ritala P (2012) Coopetition Strategy – When Is It Successful? Empirical Evidence on Innovation and Market Performance. Br J Manag 23:307–324. doi: 10.1111/j.1467-8551.2011.00741.x

Schneider S, Sunyaev A (2014) Determinant Factors of Cloud-Sourcing Decisions: Reflecting on the IT Outsourcing Literature in the Era of Cloud Computing. J Inf Technol. doi: 10.1057/jit.2014.25

Schneider S, Sunyaev A (2015) Cloud-Service-Zertifizierung. Springer Gabler

Statista (2017) Most Valuable Companies in the World 2017. In: Statista. https://www.statista.com/statistics/263264/top-companies-in-the-world-by-market-value/. Accessed 22 Nov 2017

Tilson D, Lyytinen K, Sørensen C (2010) Digital Infrastructures: The Missing IS Research Agenda. Inf Syst Res 21:748–759. doi: 10.1287/isre.1100.0318

Tiwana A (2015) Evolutionary Competition in Platform Ecosystems. Inf Syst Res 26:266–281. doi: 10.1287/isre.2015.0573

Vargo SL, Akaka MA (2012) Value Cocreation and Service Systems (Re)Formation: A Service Ecosystems View. Serv Sci 4:207–217. doi: 10.1287/serv.1120.0019

Vargo SL, Lusch RF (2016) Institutions and axioms: an extension and update of service-dominant logic. J Acad Mark Sci 44:5–23

Venkatraman N, Chi-Hyon Lee (2004) Preferential Linkage and Network Evolution: A Conceptual Model and Empirical Test in the U.S. Video Game Sector. Acad Manage J 47:876–892. doi: 10.2307/20159628

Venters W, Whitley EA (2012) A Critical Review of Cloud Computing: Researching Desires and Realities. J Inf Technol 27:179–197. doi: 10.1057/jit.2012.17

Walsham G (2006) Doing Interpretive Research. Eur J Inf Syst 15:320–330

Williamson PJ, De Meyer A (2012) Ecosystem Advantage: How to Successfully Harness the Power of Partners. Calif Manage Rev 55:24–46

Xia W, Lee G (2005) Complexity of Information Systems Development Projects: Conceptualization and Measurement Development. J Manag Inf Syst 22:45–83