Digital Infrastructure: A Service-dominant Logic Perspective

Research-in-Progress

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Abstract

Owing to the rapid and unrelenting digitalization of business ecosystems, digital infrastructure—as a new information technology artifact to conceptualize and realize interconnected information system collectives—has drawn considerable attention in information systems research. Building on the extant body of knowledge, this study synthesizes and integrates existing discourses into a theoretical framework to contribute to the conceptualization of and to prospective theorizations on digital infrastructure. This theoretical framework follows distinctive assumptions of service-dominant logic to business ecosystems and accounts for socio-technical complexity of digital infrastructure to eventually derive six theoretical foundations of digital infrastructure. While three foundations (i.e., structural integrity, structural elasticity, and ambidexterity) reflect fundamental bases of digital infrastructure, the other three foundations (i.e., connectivity, generativity, and modularity) reflect underlying mechanisms that cause and shape digital infrastructure's fundamental bases. These insights represent an overall study's first step whose next steps and the expected outcomes are also discussed.

Keywords: Digital infrastructure, Theoretical foundations, Service-dominant Logic, Socio-technical complexity, Digital business ecosystems

Introduction

> *"Digital infrastructures are a new species of IT artifact. They render industries and products increasingly information based and reshape industrial organization and services as industries undergo comprehensive digitalization"* (Tilson et al. 2010, p. 756).

Pervasive digitalization of organizational life, commonly referred to as *digital convergence*, has become the "new" reality in information systems (IS) research (e.g., Tilson et al. 2010; Yoffie 1996; Yoo 2010). Digitalization applies "digitizing techniques to broader social and institutional contexts that render digital technologies infrastructural" (Tilson et al. 2010, p. 749). Such infrastructural rendering of digital technologies has led to the evolution of a new class of information technology (IT) artifact—*digital infrastructure* (DI) (Hanseth and Lyytinen 2010; Henfridsson and Bygstad 2013; Tilson et al. 2010). IS research has witnessed an ever-growing interest in DI[1] whose unique properties and effects are becoming fundamental in understanding the effects of digitalization (Tilson et al. 2010, p. 753). Even though definitions still vary, extant research has adopted the notion of DI as a way of conceptualizing the *shift* from single organizations' IT infrastructures to networks of corporate digital infrastructures (Ciborra 2000; Tilson et al. 2010), and from *stand-alone* IS to *interconnected* system collectives (Henfridsson and Bygstad 2013, p. 908). In this study, we opt for Henfridsson and Bygstad's (2013, p. 908) definition of DI as "the collection of technological and human components, networks, systems, and processes that contribute to the functioning of an information system [entailing] both social and technical elements."

Next to this major shift in technology, organizations undergo a major business shift, too, from a one-way process of exchanging fixed asset products in traditional supply chains (i.e., neoclassical industrial perspective) to a collaborative process of value co-creation in dynamic service ecosystems (i.e., network-centric perspective) that cross traditional industry and firm boundaries (El Sawy et al. 2010). This trend has been reflected in a service-dominant (S-D) logic to business and economies (Lusch and Nambisan 2015; Vargo and Lusch 2004, 2016). Prominent IT organizations such as Salesforce.com, Amazon Web Services, IBM, Microsoft, Oracle, or SAP operate under such premise by building up cloud service ecosystems—an exemplar of service ecosystems rendering DI. These organizations act as orchestrators at the core of their cloud service ecosystem's DI (Ceccagnoli et al. 2012).

In addition, there is an evolving discourse in the IS literature to rethink the role of IT. This discourse encourages a *fusion* between business and technology instead of their investigation as two separate phenomena requiring alignment (Bharadwaj et al. 2013a, 2013b). Building on this discourse and on the two groundbreaking business (service ecosystems, S-D logic) and technology (DI) shifts, in line with Lusch and Nambisan (2015), we argue that DI has to be closely examined related to the emerging logic of service ecosystems. Crossing traditional industry and firm boundaries as well as turning the classical exchange of fixed products to a collaborative and highly interdependent co-creation of value in actor-to-actor networks inevitably brings along a significant socio-technical complexity in DI. As DIs are supposed to cater digital means for such a business context, understanding the underlying socio-technical complexity and its consequences becomes evident. To this end, we consider DI as a dynamic socio-technical phenomenon for which one should account for a simultaneous consideration of both business and technology *complexity* (as a fusion) and their relations (Benbya and McKelvey 2006; Kuhn 2006; Mocker et al. 2015).

In this study, we follow Tilson et al.'s (2010, p. 756) call for "deeper theoretical work on the notion of infrastructures" as well as for employing "new theoretical lenses to understand the paradoxical nature of change and control in digital infrastructures." To this end, we base our investigation of DI on (i) S-D logic's assumptions, as the main theoretical lens, to guide our understanding of service ecosystems; and on (ii) a socio-technical complexity approach, as the complementary theoretical lens, to simultaneously capture both the technology and business shifts in conceptualizing DI. As part of an overall, mixed-methods study, the paper at hand reports insights of a theoretical essay, to be used as a basis for further steps of the overall study. The main contribution of the currently conducted step is a theoretical framework of DI's foundations that contributes to conceptualization of and to prospective theorizations on DI. As such, we not only employ a new theoretical lens to spotlight and further conceptualize DI's social (business) aspect and its interplay with the technological aspect, but also offer a synthesis of current discourses on DI into a theoretical framework that helps scholars investigate and theorize DI.

[1] The literature uses different concepts for capturing this phenomenon (e.g., information infrastructure, e-infrastructure) (e.g., Aanestad and Jensen 2011; Broadbent et al. 1999; Hanseth and Lyytinen 2010; Hepsø et al. 2009; Sahay et al. 2009; Star and Ruhleder 1996). In line with Tilson et al. (2010) as well as Henfridsson and Bygstad (2013, p.908), we use the term digital infrastructure throughout this paper.

Research Motivation and Method

Since Star's and Ruhleder's (1996) landmark study, the volume of IS research using the notion of (digital) *infrastructure* has grown in the past 20 years. Most studies are not necessarily dealing with DI itself (Tilson et al. 2010), rather use DI as an independent variable to explain other topics of interest (e.g., Malhotra et al. 2005). Concerning studies treating DI at the center of attention, four research streams can be distinguished (Henfridsson and Bygstad 2013, p. 910): The *complexity* stream is concerned with the complexity emerging through and absorbed by DI (e.g., Braa et al. 2007). The *network* stream examines multiple human actors creating networks of organizational and technological elements (e.g., Aanestad and Jensen 2011). The *relational* stream spotlights the socio-technical relations mediated by DI among human and non-human actors (e.g., Star and Ruhleder 1996). Finally, the *strategic asset* stream is concerned with the role of DI in aligning organizations' IT resources and their strategic imperatives (e.g., Broadbent et al. 1999).

Notwithstanding recent research advances in DI, there are research gaps that motivate our research. *First*, extant literature covers different streams (e.g., complexity, network, relational, and strategic asset), settings (e.g., health, telecom, or government), levels of analysis (e.g., individual, group, organization, industry, and society), and technologies (e.g., standards, platforms, and the Internet). Even though the evolving literature makes consensus on the notion of DI in materializing the move from intra-organizational systems and individual tools (e.g., Pavlou and El Sawy 2010) toward inter-organizational and interconnected IS collectives (Ciborra 2000; Star and Ruhleder 1996), there is still a gap on what constitutes DI's concept as an emerging IS phenomenon (Aanestad and Jensen 2011; Henfridsson and Bygstad 2013; Tilson et al. 2010). The latter entails a need for a synthesis of existing diverging conceptualizations of DI to eventually extract latent, inherent themes and concepts into an integrated theoretical foundation (Tilson et al. 2010). This gap has culminated in a call for deeper theoretical works on DI employing new lenses (e.g., Henfridsson and Bygstad 2013; Lusch and Nambisan 2015; Tilson et al. 2010). *Second*, extant research employs either a static perspective to shed light on DI's structural complexity (i.e., multiplicity and interdependency of DI's elements) or a dynamic perspective to lay emphasis on DI's dynamic complexity (i.e., rate and pattern of DI's changes). Even though both perspectives contribute to exiting conceptualizations, we are lacking an integrated perspective to examine the interplay between the static and dynamic aspects that eventually provides a thorough understanding of the phenomenon of interest (Markus and Robey 1988). In particular, little focus has been drawn on the underlying mechanisms that explain the dynamics of DI evolution. *Third*, several calls for employing new theoretical lenses to not only understand the paradoxical nature of DI (e.g., Tilson et al. 2010), but also to investigate DI from business-IT fusion (e.g., Bharadwaj et al. 2013b) and from service ecosystem (e.g., Lusch and Nambisan 2015) perspectives have not sufficiently been responded so far. Since the unique properties and effects of DI have emerged to be fundamental in understanding digital convergence, we consequently argue that closing these gaps—as our overall study takes a preliminary step toward this goal—has become essential. To this end, our research employs theoretical assumptions of (i) S-D logic to capture the recent philosophical shift in business and economies as well as (ii) a socio-technical complexity approach to reflect not only social and technological aspects, but also structural and dynamic complexity of DI. Relying on the employed theoretical lenses, this study synthesizes the main concepts and themes of the existing research into a theoretical framework. Through providing an integrated view on the conceptual constituents of DI, this theoretical framework guides prospective theorizations on DI.

This research-in-progress is embedded in an overall, four-stage mixed-methods research agenda: (1) theoretical foundations of DI, (2) literature review, (3) expert study, and (4) case survey. While the paper at hand develops a theoretical framework of DI's foundations, to be used a basis for subsequent steps, the other steps contribute to an in-depth investigation of DI and empirically examine its constitutive concepts (see Table 1). **Step one**, which is within the scope of the paper at hand, is concerned with providing theoretical foundations of DI as a new class of IT artifact. In **step 1.1**, building on S-D logic and a socio-technical complexity approach, we develop an analysis framework to guide the derivation of the targeted DI's theoretical foundations. In **step 1.2**, we create a pool of studies required to uncover the theoretical foundations of DI. To this end, we include relevant studies on DI, which are published in the AIS basket-of-eight journals. We search the Business Source Premier database employing the EBSCOhost search engine without time restrictions. The 29 selected papers have the phrases "digital infrastructure" or "information infrastructure" in the title, abstract, or keywords. In addition, we include studies on and/or using S-D logic that are published in the AIS basket-of-eight journals. This added another 15 papers, most of which are part of the MISQ special issues on "Service Innovation in the Digital Age" (Barrett et al. 2015) and on "Co-creating

IT Value" (Grover and Kohli 2012). Particularly, we are interested in the studies at the intersection of S-D logic and digital convergence. In **step 1.3**, the selected 44 papers are coded based on the constituents of the analysis framework (developed in step 1.1). The emerged groups of interrelated codes are then clustered with the intention of identifying key concepts of DI. The identified key concepts are then labeled as *structural integrity*, *structural elasticity*, *ambidexterity*, *generativity*, *modularity*, and *connectivity* to reflect their main theoretical emphasis and to be used for developing a sexpartite framework synthesizing and integrating the proposed six DI foundations. The overall study's steps two to four are discussed in the last section.

Table 1. Research Design of the Overall Mixed-Methods Research Agenda

Step			Outcome	Scope
1	1.1	Develop a Theory-based Analysis Framework	An analysis framework based on the employed theoretical lenses (i.e., S-D logic and socio-technical complexity)	Paper at hand
	1.2	Select Relevant Papers	A pool of relevant papers on DI and on the implication of S-D logic in IS research from AIS basket-of-eight journals (44 papers)	
	1.3	Derive a Framework of DI's Theoretical Foundations	A classified set of theoretical foundations of DI in relation to constitutive elements of the analysis framework (6 foundations classified as *BASES* and *MECHANISMS*)	
2	Systematic Literature Review on DI		▪ An in-depth understanding of the derived theoretical foundations (from step 1) ▪ Constitutive sub-concepts/-constructs and measures of each of the foundations	Next steps
3	Expert Study		Refined, adapted, and extended set of theoretical foundations into a testable research model	
4	Case Survey		An empirical validation of the research model (from step 3) through secondary empirical data	

The next two sections of the paper at hand are dedicated to explain the analysis framework as well as the derived theoretical foundations of DI. The last section, in turn, discusses the proposed theoretical framework (containing six theoretical foundations of DI) as well as the roadmap for completing and extending our overall study.

Analysis Framework

The analysis framework deducted and explicated in this section employs both S-D logic and a socio-technical complexity approach to be used as a basis to derive the theoretical foundations of DI.

Table 2. Meta-theoretical Foundations of S-D Logic (Lusch and Nambisan 2015, p. 164)

Foundation	Definition	Description
Resource Liquefaction	Decoupling of information from its related physical form or device	**Shift from** information coupled to its related physical matter, technology, or device **to** digitized, decoupled, and more useful information easier to share with others
Resource Density	Mobilization of the best combination of resources for a particular situation—e.g., for a customer at a given time in a given place—independent of location, to create the optimum value/cost result	**Shift from** ineffective and inefficient mobilization of resources for integration (i.e., low resource presence) at a given time and place **to** mobilization of an ideal combination of contextually relevant resources in the most effective and efficient way for a particular situation (i.e., maximum resource density).
Resource Integration	Integrating different components into a total solution with all social and economic actors acting as resource integrators	**Shift from** production of fixed asset products and services **to** integration and transformation of micro-specialized resources into complex services contextually demanded by beneficiaries
Actor-to-Actor Networks	Integration of resources by all actors in a network of other actors all being potential innovators or co-creators of value	**Shift from** one-way process of *value exchange* in traditional supply chains (i.e., neoclassical industrial perspective) **to** collaborative process of *value* co-*creation* in service ecosystems (i.e., network-centric perspective)

S-D Logic. The seminal studies in marketing research (Vargo and Lusch 2004, 2008) shed light on the emergence of a paradigm shift in economic exchanges from goods-dominant (G-D) logic to S-D logic. The cornerstone of this reorientation is the notion of value co-creation to jointly create value within a *service* *ecosystem* that comprises a variety of actors, such as suppliers, partners, and customers. Central to S-D logic is the proposition that resources (e.g., operant and operand resources) do not have value per se; rather value is created and co-created when (i) resources are used or perceived as being useful by other actors in the service ecosystem and when (ii) actors actively and *jointly* contribute in the value (co-)creation process in the given service ecosystem (Vargo and Lusch 2004, 2008). As such, S-D logic and its core concept of value co-creation (e.g., Galvagno and Dalli 2014) theorize economic exchange "*not* primarily as the production and offering of tangible goods or any output (tangible or intangible), but rather as the exchange of service that occurs by one actor using its skills and capabilities for the benefit of another actor" (Lusch and Nambisan 2015, p. 156). This moves the locus of *value creation* from exchange (value-in-exchange) to use (value-in-use) so that the manifestation of actual value is not so much attached to the natural resources and technological artifacts that may be involved in *delivering* a product/service, but rather in the *usage* of the product/service in a given *context*. The first constituent of our analysis framework builds on Lusch and Nambisan's (2015) meta-theoretical foundations to grasp the shift from G-D to S-D logic (see Table 2).

Socio-technical Complexity. "The pervasive adoption and use of information technology in contemporary organizations makes the relationship between information systems and organization increasingly complex" (Henfridsson and Bygstad 2013, p. 907). According to S-D logic, contemporary organizations operate in service ecosystems and experience a shift in their economic exchanges. In addition, the adoption of DI has originated a pervasive technology shift from standalone to interconnected IS—beyond organizational boundaries. Therefore, we opt for complexity theory as a complementary lens to account for socio-technical complexity of the dialectic interplay between DI and organizations. This lens helps us capture both social and technological aspects in studying DI. Moreover, DI conceptualizes a paradigmatic shift *from* isolated dependencies within an organization *to* extended dependencies beyond organizational boundaries which, in turn, adds even more socio-technical complexity. To this end, for the second constituent of our analysis framework, we employ Xia and Lee's (2005) conceptualization of complexity since it models the increasing socio-technical IS complexity in enterprises—covering both *organizational* and *technological* complexity (organizational vs. technological 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 (2005) outline four components of IS complexity: *Structural organizational* complexity describes the multiplicity and interdependency of organizational elements (e.g., end users, project team, top management or external contractors/vendors). *Structural IT* complexity describes the multiplicity and interdependency of technological elements (e.g., technology platforms, 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). Finally, *dynamic IT* complexity describes the rate and pattern of changes in the IT environment (e.g., changes in infrastructure, architecture, and development tools).

Through putting together the theoretical assumptions of both S-D logic and socio-technical complexity, we derive our analysis framework. As illustrated in Table 3, the constitutive elements of the analysis framework guide the derivation of DI's theoretical foundations.

<table>
<tr><th colspan="6">Table 3. Analysis Framework</th></tr>
<tr><td rowspan="6">S-D Logic: From value-in-exchange in supply chain to value-in-use in service ecosystem</td><td colspan="5">Socio-technical Complexity:
From either organizational or technological view on complexity to an overarching view as a fusion between both</td></tr>
<tr><td>Increase in:</td><td>Structural Organizational Complexity</td><td>Structural IT Complexity</td><td>Dynamic IT Complexity</td><td>Dynamic Organizational Complexity</td></tr>
<tr><td>Resource Integration</td><td colspan="4" rowspan="4">Theoretical Foundations of Digital Infrastructure:
From standalone IS to interconnected IS collectives</td></tr>
<tr><td>Resource Liquefaction</td></tr>
<tr><td>Resource Density</td></tr>
<tr><td>Actor-to-Actor Network</td></tr>
</table>

A Framework of Digital Infrastructure's Theoretical Foundations

Guided by the analysis framework, we coded the selected 44 papers. This effort resulted in extracting a set of interrelated codes, which are subsequently clustered and integrated into a framework of digital infrastructure's theoretical foundations. Table 4 shows how DI's theoretical foundations are related to and derived from the constituents of the analysis framework.

The derived framework encompasses two sets of theoretical foundations for DI namely, *fundamental bases* and *fundamental mechanisms* (see Table 5). Fundamental bases—labeled as *bases*—refer to the fundamental nature of DI—its *raison d'être*. This set of foundations comprises *structural integrity*, *structural elasticity,* and *ambidexterity*. They are drawn based on the dualism of *integrity* and *elasticity* (e.g., Ciborra 2000; Farjoun 2010; Tilson et al. 2010) in that DI seeks both for stabilization to exploit the given network/ecosystem and for dynamism to explore new avenues of resource integration and resource mobilization in adapting to external stimuli. Simultaneously, DI strives for a balance between integrity and elasticity (*ambidexterity*). Fundamental mechanisms—labeled as *mechanisms*—refer to the underlying explanatory mechanisms that cause and shape DI's fundamental *bases* (Bunge 2004). This set of foundations comprises *generativity*, *modularity*, and *connectivity*. Finding these *mechanisms* is essential for prospective theorizations since they help us not only understand but also manage the phenomenon of interest (Bunge 2004).

Table 4. Theoretical Foundations of Digital Infrastructure in relation to Constituents of the Analysis Framework

Socio-technical Complexity: From either organizational or technological view on complexity **to** an overarching view as a fusion between both

S-D Loigc: From value-in-ex-change in supply chain **to** value-in-use in ecosystem

Increase in:	*Structural Organizational Complexity*		*Structural IT Complexity*		*Dynamic IT Complexity*		*Dynamic Organizational Complexity*	
Resource Integration	-	(1) Macro-Perspective, Cross-sectional, Standardization, Exploitation, Equilibrium		-	(5)	(2) Micro-Perspective, Longitudinal, Autonomy, Exploration, Evolution		(5)
Resource Liquefaction			(6)					
Resource Density	(4)			(4)	-			-
Actor-to-Actor Network			(3)					

Structure of Digital Infrastructure:	(1) Structural Integrity (BASIS)	↔	(4) Connectivity (MECHANISM)
Dynamics of Digital Infrastructure:	(2) Structural Elasticity (BASIS)	↔	(5) Generativity (MECHANISM)
Balancing Structure and Dynamics:	(3) Ambidexterity (BASIS)	↔	(6) Modularity (MECHANISM)

Foundation 1. Structural integrity of digital infrastructure is the fundamental basis of control and stability. Structural integrity refers to "the nature of ties or relationships that hold the diverse actors together in a network" (Lusch and Nambisan 2015, p. 164). DIs are paradoxical (Lusch and Nambisan 2015; Tilson et al. 2010; Vargo and Akaka 2012) as their generative nature (Akaka and Vargo 2014; Henfridsson and Bygstad 2013) causes the issues of change and control (Ciborra 2000). Extant literature approaches change and control as a *duality* (Farjoun 2010): DIs need to be organized in ways that are simultaneously *stable* and *flexible* (paradox of change) as well as offer both *control* and *autonomy* (paradox of control) (Tilson et al. 2010). Covering stability and control of these two paradoxes, structural integrity provides a macro-perspective on the multiplicity, diversity, and interdependency of existing both organizational and technological nodes and links in a given network (i.e., *structural complexity*). To this end, efficient and effective *resource integration* of structurally complex sets of *liquefied resources* in *actor-to-actor-networks* require stability and control of DIs for actors to exchange services. Control and stability converge actor-generated institutions and institutional arrangements through which value co-creation in service ecosystems is coordinated (i.e., as one of the axioms of S-D logic) (Vargo and Lusch 2016). Apple's

iTunes platform, for example, exercises strict control and stability over application approval, payment terms, architectural rules, and many aspects of the internal operations of applications. This control provides a reliable and stable low-cost entry for a large number of developers to co-create applications. Yet, developers share a "love-hate" relationship with the infrastructure's restrictions since their autonomy decreases.

Foundation 2. Structural elasticity of digital infrastructure is the fundamental basis of autonomy and change. Structural elasticity refers to "the different ways of organizing actors to suit varied innovation opportunities in a network" (Lusch and Nambisan 2015, p. 164). Conversely to structural integrity (Foundation 1), structural elasticity covers *flexibility* and *autonomy* in the duality between paradoxes of change and control (Ciborra 2000). It provides a micro-perspective on the rate and pattern of changes over time (i.e., cross-sectional) through actors or relations joining, adapting, or leaving a DI—both organizational and technological ones (i.e., *dynamic complexity*). For instance, an organization may decide to shut down one of its IS causing feedback loops in the overall DI. To this end, DIs should be flexible enough to grant loosely coupled actors a fair degree of agency to act autonomously (Weick 1976). This implies that DIs afford and constrain the ease with which different configurations of resources and actors (and their roles and responsibilities) can participate in a *service ecosystem*—directly affecting *resource density*. The high level of loosely coupling in Apple's ecosystem, for example, enables structural elasticity in its DI. Therefore, users and application developers are free in their decision if and how to adapt to new environmental stimuli and competitive pressures and, in turn, create new service innovation opportunities. Arbitrarily changing n-lateral relations between actors at the micro-level, for instance, affords value co-creation without explicit involvement of a lead-actor.

Foundation 3. Ambidexterity of digital infrastructure is the fundamental basis of balancing integrity with elasticity. Ambidexterity of DIs refers to the above-mentioned paradoxical nature of DI in Foundations 1 and 2: "While digital infrastructures can appear durable for a time, their inherent scalability and flexibility fosters extraordinary growth in scale and scope" (Tilson et al. 2010, p. 753). Structural elasticity is important in actor-to-actor-networks since it allows actors to have agency in their rates and patterns of changes of organizational and technological elements. Structural integrity is important since it facilitates the structures that are created to enable human and non-human actors to exchange services. Concurrently, elasticity and integrity may potentially conflict with each other causing tensions between the two (Lorenzoni and Lipparini 1999; Lusch and Nambisan 2015). To this end, we refer to ambidexterity of DIs as the fundamental basis of balancing both to make an actor-to-actor network efficient and effective at the same time, strengthening both structural elasticity and structural integrity (O'Reilly and Tushman 2008). As such, since an overemphasis of one side leads to obstruction, DI should facilitate the trade-off between exploitation and exploration (Miller and Martignoni 2016; Stettner and Lavie 2014): they should strengthen the existing overall topology of actor-to-actor networks, thereby solidifying structural integrity. They should also enable new rates and patterns of change through novel connections among actors, thereby enhancing elasticity. Apple's ecosystem, for instance, offers a stable portfolio of multiple, diverse, and interdependent hardware, software, and organizational resources without constraining developers in flexibly exploiting new application opportunities.

Foundation 4. Connectivity is the fundamental mechanism of digital infrastructure's structural integrity. Connectivity refers to a mechanism "which, *ceteris paribus*, reduces communication cost and increases its speed and reach" (Lyytinen et al. 2016, p. 8). This foundation captures the efficiency provided by DIs to service ecosystems in enhancing *resource density* in *actor-to-actor networks* through reduced communication costs and increased resource mobilization (Majchrzak and Malhotra 2013; Sambamurthy et al. 2003; Sambamurthy and Zmud 2000). Digital connectivity enhances resource density by amplifying the distribution of resources and enabling coordination and collaboration among innovation participants (Lyytinen et al. 2016). Existing actors in a given network are supported in the mixing and matching of resources within and across service platforms. Digital connectivity through DIs includes both searching for appropriate resources (given a specific value creation context) and bundling resources in (or transporting resources to) a location (Lusch and Nambisan 2015). Therefore, connectivity is the mechanism for the exploitation of a given network. For instance, Apple has demonstrated the power of its ecosystem through its connectivity across hardware, software, and services based on iPhone, iPad, Mac, and Apple Watch. This represents a competitive advantage over rival platforms through connectivity.

Foundation 5. Generativity is the fundamental mechanism of digital infrastructure's structural elasticity. Generativity refers to "the capacity of a self-contained (digital) system to generate new outputs, structures or behaviours endogenously through the participation of uncoordinated third-party actors without deliberate planning from the originator of the system" (Lyytinen et al. 2016, p. 7). Concerning the evolution of DI, generativity defines what constitutes structural elasticity of DI (Henfridsson and Bygstad 2013). In this vein, a generative mechanism is "one of the processes in a concrete system that makes it what it is—for example, metabolism in cells, interneuronal connections in brains" (Bunge 2004, p. 182). A new kind of unbounded service divergence—a symptom of generativity—affords new ways and forms of *resource integration* which results in new digital innovations of services, products, contents, and business models such as eBay or Netflix (Tilson et al. 2010). In this respect, the rates and patterns of *dynamic complexity*—technological and organizational—increase. In turn, this service divergence spurs *resource liquefaction* in that the heterogeneity, integration, and recombination of digitized resources increase (Lyytinen et al. 2016). The Android ecosystem, for instance, has fewer standards compared to the iPhone, creating a freer but also more chaotic environment for developers. Android emphasizes the generative aspects in that they allow for interaction and information exchange between the programs and databases locally installed on a mobile device. This results in more applications compared to competing mobile ecosystems.

Foundation 6. Modularity is the fundamental mechanism of digital infrastructure's ambidexterity. Modularity refers to the degree to which a system's components may be separated and recombined (Aanestad and Jensen 2011; Hanseth et al. 1996). Hanseth et al. (1996) argue that DIs "consist of a highly complex and extensive physical network of interconnected modules of communication technology. The only feasible way to cope with such a network is by modularization" (ibid. 1996, p. 416). DI modularity is presented in the extant literature as a fundamental mechanism in adapting to increasing *complexity* (Aanestad and Jensen 2011; Boudreau 2007; Braa et al. 2007), a mediator for the conflicting poles of standardization and flexibility. As such, actors in the ecosystem gain access to suitable IT modules in order to combine IT resources in new ways that match the value co-creation context and that are ready to be combined (Lusch and Nambisan 2015). To this end, modularity affords opportunities for facilitating ambidexterity in DI. Apple's ecosystem is a bad example in this regard. With its monolithic architecture, applications can only be integrated into a single system (e.g., the Mail app in iOS). Conversely, the highly modular personal computer ecosystem with its plug-and-play architecture is an example of a modularity since computers and peripheral devices can be separated and recombined independent of the producer (Tiwana 2013).

Table 5. Theoretical Foundations of Digital Infrastructure

Label	**Foundation**	**Description**
F1. Integrity *BASIS*	Structural integrity of digital infrastructure is the fundamental basis of control and stability.	DI seeks for stabilization to exploit the given actor-to-actor network. Thus, the nature of ties or relationships in DI should hold the diverse actors together.
F2. Elasticity *BASIS*	Structural elasticity of digital infrastructure is the fundamental basis of autonomy and change.	DI seeks for dynamism to explore new avenues of resource integration adapting to external stimuli. Thus, different ways of organizing DI actors should suit varied innovation opportunities.
F3. Ambidexterity *BASIS*	Ambidexterity of digital infrastructure is the fundamental basis of balancing integrity with elasticity.	DI seeks for a balance between structural integrity and structural elasticity. Thus, DI should allow for both control and stability as well as for autonomy and change.
F4. Connectivity *MECHANISM*	Connectivity is the fundamental mechanism of digital infrastructure's structural integrity.	Connectivity refers to causal structures explaining the processes yielding in network exploitation. Connectivity of DI reduces communication cost and increases its speed and reach.
F5. Generativity *MECHANISM*	Generativity is the fundamental mechanism of digital infrastructure's structural elasticity.	Generativity refers to causal structures explaining the processes yielding in network exploration. Generativity of DI endogenously generates new outputs, structures or behaviors.
F6. Modularity *MECHANISM*	Modularity is the fundamental mechanism of digital infrastructure's ambidexterity.	Modularity refers to causal structures explaining the processes yielding in DI balance. Modularity of DI increases separation and recombination of infrastructure components.

Discussion and Next Steps

As an attempt to capture the essence of digital infrastructure, the primary step of our overall study synthesizes six theoretical foundations of digital infrastructure in a framework, grounded on S-D logic and complexity theory as two guiding lenses. The proposed foundations draw on the dualism of structural integrity and elasticity of digital infrastructure. This discourse closely relates to digital infrastructure's complexity, where we distinguish structural and dynamic complexity. If structural complexity remains uncontrolled and goes beyond certain limits, it will significantly constrain the elasticity of digital infrastructure. If dynamic complexity remains uncontrolled and goes beyond certain limits, the structure of the digital infrastructure will diverge. In this respect, we can consider a digital infrastructure as an IT artifact that seeks for stabilization to exploit the given network/ecosystem (*structural integrity*), deals with dynamism to explore new avenues of connections in adapting to external stimuli (*structural elasticity*), and simultaneously strives for a balance between structural integrity and elasticity (*ambidexterity*). We further delineate three fundamental mechanisms that cause and generate digital infrastructure's structural integrity (through *connectivity*), structural elasticity (through *generativity*), and ambidexterity (through *modularity*).

As outlined in the research method section, the paper at hand reports the resulted insights of the **step one** of our overall study. Building on the derived theoretical foundations form the first step and drawing on Webster and Watson's (2002, p. xvi) guideline, **step two** is concerned with an extensive, systematic literature review on digital infrastructure. The goal is to elaborate on the six theoretical foundations through identifying their constitutive sub-concepts/constructs and measures. We will extend the search terms, based on the outlined theoretical foundations, and broaden the search process to cover a wider range of outlets. To this end, we will collect papers from the AIS basket-of-eight journals as well as from the leading journals listed in the Harzing Journal Quality List[2]. We will further go backward and forward and add articles from conference proceedings and books on an *ad hoc* basis and eventually code all the relevant collected papers based on the six foundations. In **step three**, we will carry out an expert study, for which we consider focus groups, to validate, refine, and—if required—adapt or extend the foundations and their constitutive constructs and measures to reach a testable research model. Finally, **step four** is concerned with an empirical validation of the research model (from step 3) through secondary empirical data (Lee 1991; Walsham 2006). To this end, we will employ a case survey based on (i) 41 real-world instances of digital infrastructure collected by Henfridsson and Bygstad (2013, p. A5) and (ii) new cases of digital infrastructure based on our extensive search and literature review in *step two*. Adopting a case survey methodology allows to quantitatively analyze patterns across case studies, thereby bridging "the gap between nomothetic surveys and idiographic case studies to combine their respective benefits of generalizable, cross-sectional analysis and in-depth, processual analysis" (Larsson 1993, p. 1515). In doing so, we will empirically validate and/or extend the derived research model from *step three*.

This study integrates into and follows the existing discussions on the paradoxical nature of digital infrastructure—considering both structural integrity and structural elasticity as well as balancing the potential conflicts between them (Aanestad and Jensen 2011; Hanseth et al. 1996; Tilson et al. 2010). In answering the call for deeper theoretical work on the notion of infrastructure (e.g., Henfridsson and Bygstad 2013; Lusch and Nambisan 2015; Tilson et al. 2010), and through employing new theoretical lenses, our study extends the extant conceptualizations by proposing and further validating (in the next steps) a set of theoretical foundations that elaborate on the fundamental bases and underlying mechanisms of digital infrastructure. We thus contribute to extant research with the offered conceptualization that helps identify and integrate the salient themes and concepts that are of profound value to the growing discipline of digital infrastructure.

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[2] http://www.harzing.com/download/jql_subject.pdf

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