THE GENERATIVE CAPACITY OF DIGITAL ARTIFACTS: A MAPPING OF THE FIELD

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Abstract

The concept of generativity as the capacity of a technology or a system to be malleable by diverse groups of actors in unanticipated ways has recently gained considerable traction in information systems research. We review a sample of the body of knowledge and identify that scholars commonly investigated generativity in conjunction with digital infrastructures and digital platforms, both of which are complex, networked, and evolving socio-technical systems. Interestingly, other types of digital artifacts have been neglected, despite our initial assumption that the distinct attributes (e.g., reprogrammability, distributedness) of any digital artifact match well with generativity. The literature review also reveals that innovation brought about heterogeneous groups of actors is universally regarded as the goal of generativity, discounting the possibility of exploiting generative systems towards other valuable ends such as organizational agility. Furthermore, scholars commonly discuss generativity in conjunction with the logic of modularity, leading to unresolved questions on how these two concepts might complement each other. Another important contribution of this paper is the systematization of various meanings of generativity, spanning from the philosophical–e.g., generative mechanisms in critical realist research–to a more literal understanding, for instance generativity as synonym to 'creation of a particular solution'.

Keywords: generativity, innovation, digital artifact, infrastructure, platform, modularity.

1 INTRODUCTION

Fueled by recent calls for research (Tilson et al. 2010; Yoo et al. 2010) the *generativity* concept, defined by Zittrain as *the capacity of a technology or a system to be malleable by diverse groups of actors in unanticipated ways* (2006; 2008), has gained some prominence in the information systems (IS) research community. Consistent with the mentioned calls for research, recent literature explored this concept in the context of *digital infrastructures* (cf. Tilson et al. 2010) and *digital platforms* (cf. Yoo et al. 2010) and how it drives innovation. For instance, Ghazawneh & Henfridsson (2013) discussed how platform owners design and tweak boundary resources such as APIs (application programming interfaces) to balance generative capacity with control concerns; Boudreau (2012) investigated how the number of third-party application developers increase the attractiveness of a platform through collective effects of high variety and innovation; and Selander et al. (2013) ask how third-party actors choose the platforms in which they intend to participate and how they extract value from their share of innovation.

Zittrain's understanding of generativity[1] was mostly borne out of law discourses (Zittrain 2008: chapter 4) before it entered the IS domain. When a new concept is adopted, a clear characterization in relation to existing scholarly discourses is called for, in order to grasp the phenomenon behind the term. In light of Yoo's (2013) call for research to examine generativity as novel contribution to innovation and technology management research, we regard such a characterization to constitute a crucial first step towards this goal. With this paper we therefore seek to trace how IS scholars grafted generativity into existing IS-related roots (cf. Truex et al. 2006), that is in which established discourses within IS research this newly adopted generativity concept has been interwoven. We formulate our goal accordingly:

In relation to which IS discourses has Zittrain's generativity concept been commonly discussed?

Before we can tackle this substantial question, we must eliminate any terminological ambiguity first. As Avital & Te'eni (2009) pointed out in their own alternative conceptualization of generativity, in its broadest sense the term *"refers to a capacity of producing or creating something"* (p.2), leading them to conclude that the term has been utilized to mean different things in different research contexts within social sciences. The obvious danger is that the uninitiated scholar is puzzled when the same term is employed to mean fundamentally different things (cf. Gerring 2012). As a discipline that habitually borrows theories and concepts from other fields (Baskerville & Myers 2002), IS research seems particularly prone to evoking such potential misunderstandings. As preparatory step we hence aim to distinguish Zittrain's concept of generativity from other meanings carrying the same term in IS research.

We start by introducing the generativity concept and placing it in the context of digital artifacts. Then we describe how we tackled the research question and elucidate our rationale for proceeding as we did. We continue by briefly presenting the different meanings of generativity, as to unravel any terminology issues. Equipped with a better grasp of the relevant knowledge base, we focus the following discussion on the scholarly discourses around generativity, approaching the topic from two slightly different angles: first, we trace from which roots IS scholars commonly drew when examining generativity. Second, we analyze which digital artifacts have been proposed in the salient literature to carry generative capacity. Finally, we identify the main shortcoming of this paper and suggest selected avenues for future research.

2 GENERATIVITY IN THE CONTEXT OF DIGITAL ARTIFACTS

With an ever increasing share of physical artifacts complemented by digital components or fully replaced by digital artifacts, digital technologies become the dominant source for innovation (Lyytinen & Yoo 2002). According to widely accepted estimates about 80% of all innovations in the automotive industry are directly related to novel uses of digital technologies, just to name one example (Leen & Heffernan 2002; Mossinger 2010). This push into the digital realm increases competitive pressure and simultaneously affords unprecedented innovation across industries (Bharadwaj et al. 2013). Several

[1] When mentioning *generativity* hereafter, we refer to Zittrain's conceptualization of the term if not otherwise stated.

scholars argued that digital artifacts differ distinctively from their physical counterparts and concluded that organizations cannot deal with digitization without considerably altering their approach to doing business. For instance, Svahn & Henfridsson (2012) distinguish two *innovation regimes*, with the *product innovation* regime rooted in the physical realm and the *IT innovation* regime dealing with the peculiarities of the digital realm. The authors contend that the imbrication of physical and digital artifacts requires organizations to become proficient in both innovation regimes simultaneously.

To provide a satisfactory account of the numerous narratives around the reciprocal relationships of technological advancement and organizational change, it would be necessary to trace back to the pioneering work on socio-technical systems some six decades ago (Emery & Trist 1965; Trist & Bamforth 1951). For the purpose of this paper and acknowledging the resulting limitations, we allow ourselves to regard Zittrain's work on generativity as departure point. In his foundational article published in 2006, the author suggests that the *generative capacity* of digital technologies in general and of the internet in particular lies at the core of wide-spread and distributed innovation, creativity, and entrepreneurial activity associated with these technologies (cf. Chesbrough 2003; Hippel 2005). He defines generativity as *"a technology's overall capacity to produce unprompted change driven by large, varied, and uncoordinated audiences"* (Zittrain 2006: p.1980). In his successive book, the author refined this definition, suggesting that generativity *"is a system's capacity to produce unanticipated change through unfiltered contributions from broad and varied audiences"* (Zittrain 2008: p.70). With this expansion to a systems perspective, the author arguably intends to capture three aspects of generativity: first, that technologies can drive individual and collective creativity, for instance through providing tools for artistic expression, or by facilitating collaboration on long distances (Zittrain 2008: p.94). Second, that only through the participation of humans the generative capacity of a technology can be realized (Zittrain 2008: p.90). And third, that innovation happens on different layers–e.g., technology, content, and society–each of which may possess generative capacity on their own (Zittrain 2008: p.96).

Further disseminating what makes a system generative, Zittrain (2008: chapter 4) suggests five characteristics of generativity, namely: leverage, adaptability, ease of mastery, accessibility, and transferability. *Leverage* refers to the extent by which a system actor's productivity is increased compared to an actor performing outside the system–similar to the metaphor of a computer being like a bicycle for the mind (Krainin & Lawrence 1990). *Adaptability* indicates how malleable a system is for application in many and varied contexts. *Ease of mastery* denotes how understandable a system is and also how much effort an actor must put into becoming proficient to adapt it. *Accessibility* reflects how low the barriers of entry are. Finally, *transferability* signifies how readily changes in one part of the system can be conveyed to other parts of the system or distributed to anther system instantiation.

This concept of emergent change and innovation resonates within IS research, because it matches well with characteristics of digital artifacts, which we draw from Kallinikos et al. (2013). They distill four immediate characteristics (interactive; editable; reprogrammable; distributed) and three corollary attributes (modular; granular; reflexive) of digital artifacts. *Interactivity* denotes the possibility to explore a digital artifact, its individual components, and dependencies. *Editability* relates to the possibility of modifying the artifact while leaving its logical structure unchanged. *Reprogrammability* reflects the possibility of releasing a digital artifact from its immediate use context, modify its structure, and repurpose it. *Distributedness* signifies that digital artifacts are not confined to any physical or institutional borders. *Modularity* refers to the distinct quality of modularized digital artifacts not to be bound to a fixed product architecture, meaning that individual modules of a complex digital artifact can be transferred to completely unrelated use contexts. *Granularity* stands for the inherent decomposability of digital artifacts, down to their basic binary representation, and for the associated possibility to modify both an insignificant and a substantial part of the artifact on different levels of abstraction. Lastly, the *reflexive dynamics* of digital artifacts carries the notion that any access, assembly, or otherwise manipulation can only be performed through making use of other digital artifacts. Consequently, any domain in which digital artifacts enter will invariantly see an increase of digital artifacts over time.

In Table 1, we give some illustrative examples from IS literature in which the use of digital artifacts are accounted to have led to an innovative outcome. For each presented example we singled out one digital artifact attribute that we would argue played a central role in creating the innovation. Furthermore, we highlighted one of the five generativity attributes to which the example may be associated with. For instance, Boland et al. (2007) *(example 14)* demonstrate how the *reflexive dynamics* of digital artifacts–in this case novel *3D visualization technology* which was adopted by one architect company–led to a ripple effect, sparking digital innovation throughout the heterogeneous partner network of the focal firm. These dynamics also constantly reshaped how the focal firm was able to carry out work, hence suggesting that changes brought about 3D visualization in one part of the partner network *transferred* to another part, all without a central actor planning or overseeing this development.

	Illustrative example from IS literature (digital artifact highlighted in *italics*)	**Digital artifact attribute**	**Generativity attribute**
01	New mass-personalized *content platforms* such as Last.fm (Oestreicher-Singer & Zalmanson 2013)	Interactivity	Leverage
02	Design features of *self-service technologies* for encouraging initial use (Meuter et al. 2005)	Interactivity	Accessibility
03	*Commenting and sharing functionality* as means for content to "go viral" (Yoo 2010)	Editability	Leverage
04	*Hyperlinking* as essential mechanism to provide cross-references and to let users browse the web (Shapiro & Varian 1999)	Editability	Ease of mastery
05	Achieving high level of product quality in *open source software* development through social controls (von Krogh et al. 2012)	Reprogrammability	Adaptability
06	Improving the *control software* of embedded systems after the product has been shipped (Lee & Berente 2012)	Reprogrammability	Transferability
07	Convergence of *devices, distribution channels, and markets* (Tilson et al. 2010)	Distributedness	Leverage
08	Distributed information gathering and sharing via informally organized *social software* (von Krogh 2012)	Distributedness	Ease of mastery
09	Exploiting existing *signal processing module* to rapidly develop a new product (Woodard et al. 2013)	Modularity	Adaptability
10	Design and tuning of *APIs* to achieve desired levels of changeability and control (Ghazawneh & Henfridsson 2013)	Modularity	Accessibility
11	*Digital platforms* and competition of ecosystems (Tiwana et al. 2010)	Granularity	Adaptability
12	Collaborative, dialectic discourse on *ideation platforms* (Majchrzak & Malhotra 2013)	Granularity	Transferability
13	Large-scale *information infrastructure* design aimed at cultivating a growing installed base (Hanseth & Lyytinen 2010)	Reflexive dynamics	Accessibility
14	Wakes of innovation in temporary firm networks following the introduction of *3D visualization* in one firm (Boland et al. 2007)	Reflexive dynamics	Transferability

Table 1. Illustration of links between digital artifacts attributes and generativity attributes

It is worth noticing that the provided examples and their suggested associations are merely illustrative and thus incomplete. They were compiled to serve as a face-value test of how useful the proposed attributes of digital artifacts and of generativity might be to rationalize innovative outcomes across a wide range of scenarios. We argue that a systematic investigation of each example would uncover additional relationships between the attributes not shown in Table 1 yet. For instance, Boland et al. (2007) mention that 3D visualization not only caused an innovation ripple effect, but furthermore that the *distributedness* of digital construction models was *leveraged* to increase knowledge exchange between the project partners. These seemingly strong ties between digital artifacts and generative capacity might be a major reason why IS scholars became interested in this field of research (Yoo 2013).

3 RESEARCH METHOD

For answering the research question we turned to reviewing publications that discuss generativity in IS research and to describing the identified themes in summary (cf. Rowe 2014). The review aimed (1) to uncover which different concepts were attached the ‘generativity’ label by the IS community, and more substantially, (2) to reveal to which existing discourses within the IS discipline Zittrain’s generativity concept has been commonly related to. We followed the recommendations of Cooper (1998) and conducted research along the five logical stages of problem formulation, literature search, evaluation, analysis, and presentation. In doing so, we greatly profited from suggestions to increase process quality and to avoid potential errors associated with each of these stages. This review is aimed at the IS research community, therefore we confined literature search to the eight journals considered to be leading (AIS 2011). A recent bibliographic analysis provided solid indication that articles published in these outlets are good proxies for capturing the most visible conversations in the IS community (Lowry et al. 2013). An exhaustive review of all IS publications was beyond the objective of this paper, so we decided not to apply a cascading search strategy involving backward and forward search or the gradual expansion of the target outlets. We did however apply a very broad search strategy within the selected journals: we searched the full text for any occurrence of the words *generativity* or *generative*, without further specification. This search was carried out on February 13, 2015 and yielded 130 hits. We excluded all articles that carried the search term in their reference section only. As an exception, we included the article from Selander et al. (2013), because the authors clearly related their research to a particular conceptualization of generativity. We also excluded all articles that employed the searched-for-term merely as an attribute. For instance, Huang et al. (2014) call one approach to instill ambidexterity *opportunity-generative* (i.e., to identify/create business opportunities), but do not further elaborate on this term. In total, the search strategy resulted in a review sample of 52 publications for further evaluation and analysis. The distribution among the individual outlets is shown in Table 2.

#	Source	Database	Hits	Relevant
1	EJIS (European Journal of Information Systems)	Proquest	37	13
2	ISJ (Information Systems Journal)	Wiley	28	6
3	ISR (Information Systems Research)	Informs	3	3
4	JAIS (Journal of the Association for Information Systems)	Aisel	14	7
5	JIT (Journal of Information Technology)	Proquest	18	10
6	JMIS (Journal of Management Information Systems)	Ebsco	--	--
7	JSIS (Journal of Strategic Information Systems)	Sciencedirect	23	6
8	MISQ (Management Information Systems Quarterly)	Ebsco	7	7
			130	52

Table 2. Literature search results

Subsequently, we coded the retained articles according to the scholarly discourse from which they borrowed their understanding of generativity. For example, Lambert & Peppard (1993: p.192) draw from organizational learning literature, and specifically refer to the work of Argyris (1976) when they conceptualize *“generative or double loop learning (as) (…) new ways of looking at the world, challenging assumptions, goals, and norms”*. When no discernible source was apparent, we deducted the scholarly discourse directly from the analyzed paper. With the aim to increase parsimony, we merged categories in a second round when the topics of the papers appeared to be sufficiently closely related. For example, this led us to collapse all articles discussing issues of organizational knowledge and organizational learning into a single category. This procedure resulted in 12 remaining categories related to scholarly discourses which developed one or more meanings of generativity.

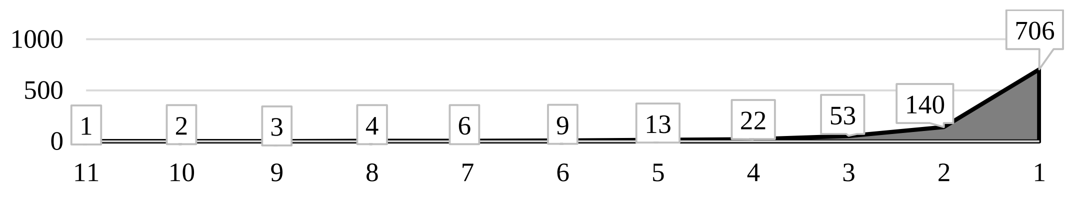

Figure 1. Number of sources (y-axis) referenced in at least n papers (x-axis)

For complementing data collection pertaining the research question, we started with the subset of 14 papers that follow Zittrain’s generativity concept. We grouped those articles according to the type of digital artifact they focused on, resulting in 3 categories. We also extracted the bibliographic information of the 14 papers, which yielded 959 entries, of which 706 were unique. Figure 1 above depicts how many source papers (y-axis) were referenced at least n times (x-axis). For example, two sources were mentioned at least 10 times (one source 11 times, and another one 10 times). We were interested in the main sources from which the 14 papers collectively drew. We decided to include those sources for further analysis which were mentioned by at least one quarter of all papers, which we found to be a reasonable cut-off value. This led to 22 sources which were referenced at least 4 times. For clarification and illustrative purposes, Figure 2 depicts the resultant citation network, with the directed edges denoting the referencing direction and the color shading indicating the number of references.

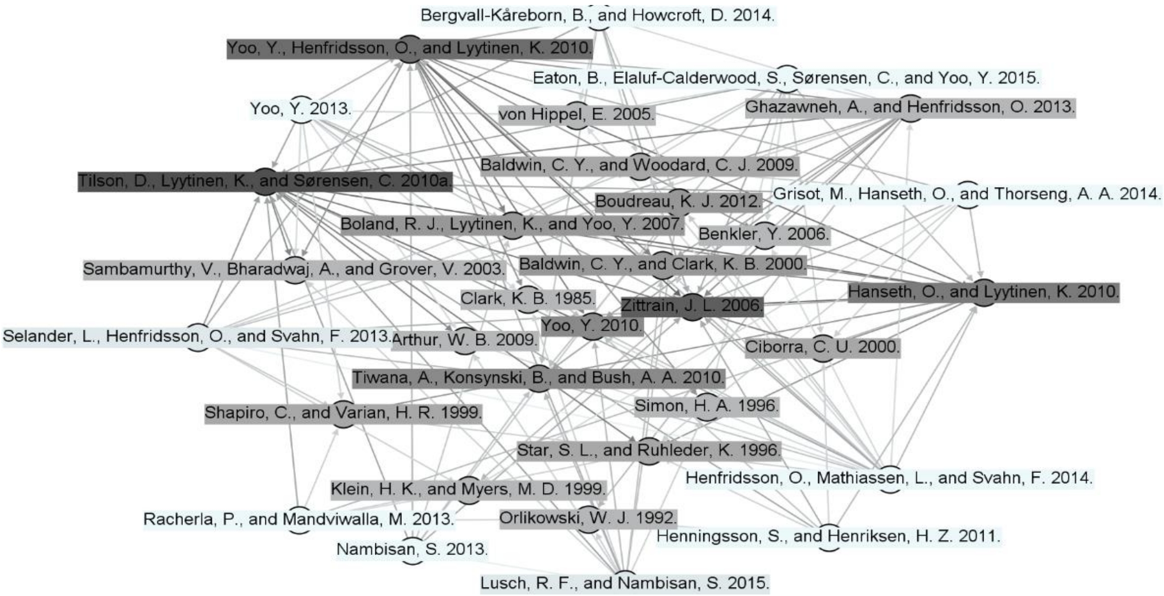

Figure 2. The 14 sample papers and the 22 sources which were referenced at least 4 times

We discarded four referenced articles for further evaluation because these were cross-references within our sample of 14 (Ghazawneh & Henfridsson 2013; Hanseth & Lyytinen 2010; Tilson et al. 2010; Yoo et al. 2010). We also dropped Zittrain's (2006) article on generativity and Klein & Myers' (1999) paper on how to conduct interpretive case study research. Analogous to the approach towards answering the first research question, we then coded the remaining 16 sources according to the scholarly discourse in which they were mentioned in the referencing articles, and merged closely related categories in a second round. This resulted in 6 distinct categories, showing which research streams were most commonly discussed in the 14 papers and thus discussed in conjunction with Zittrain's generativity concept.

4 THE MANY MEANINGS OF GENERATIVITY IN IS RESEARCH

We stated in the introduction that whenever a discipline habitually borrows concepts and theories from other areas, it is likely that the *same terminology* will be used to mean *different things*, which might puzzle a researcher new to a particular topic. The results, summarized in Table 3, show that indeed very heterogeneous concepts have been labeled with the *generativity* term. The associated meanings span from the philosophical–like the *generative mechanisms* central to critical realist research–all the way down to a more literal understanding of generativity in design ethnography as *creating a particular solution*. The first occurrence of *generativity* in our sample dates from 1985 (Lyytinen 1985), but 23 (i.e., nearly half) of the articles were published since 2013. Mapping the *generativity landscape* therefore seems to be a useful contribution to a timely scholarly conversation. Owing to the limited ambition of this article we refrain from summarizing the different scholarly discourses in which the generativity term plays a role and refer the interested reader to the reference literature collected below. For the remainder of this paper we focus exclusively on Zittrain's understanding of generativity, i.e. *the capacity of a technology or a system to be malleable by diverse groups of actors in unanticipated ways*.

Scholarly discourse	Meaning(s) of generativity	Referenced literature (selection)	Articles applying referenced meaning of generativity	#
Law discourses, in particular on free software and commons	Generativity of technologies and systems as capacity to be malleable by diverse groups of actors in unanticipated ways	Zittrain 2006, 2008	Bergvall-Kåreborn & Howcroft 2014; Eaton et al. 2015; Ghazawneh & Henfridsson 2013; Grisot et al. 2014; Hanseth & Lyytinen 2010; Henfridsson et al. 2014; Henningsson & Henriksen 2011; Nambisan 2013; Tilson et al. 2010; Yoo et al. 2010; Yoo 2013	14
		Tilson et al. 2010; Yoo et al. 2010	Lusch & Nambisan 2015; Racherla & Mandviwalla 2013; Selander et al. 2013	
Critical realism	Generative mechanisms as structures with enduring properties that are capable to cause observable events	Bhaskar 1978, 1998	Henfridsson & Bygstad 2013; Klecum et al. 2014; Lyytinen & Newman 2008; Volkoff & Strong 2013; Walsh 2014	11
		Pentland 1999	Avgerou 2013; McLeod & Doolin 2012	
		Bourdieu 1973, 1998	Schultze & Boland 2000	
		Harré & Madden 1975	Chae & Poole 2005	
		Myers & Klein 2011	Cecez-Kecmanovic 2011	
		Roberts 2006	Chatterjee & Sarker 2013	
Organizational knowledge & organizational learning discourses	Generativity as basis for creative work; generative dance of knowledge and knowing; double-loop and generative learning; generative variation		Orlikowski 2006	7
		Orlikowski 2006	Galliers 2006; Swan 2006	
		Cook & Brown 1999	Pozzebon & Pinsonneault 2012	
		Argyris 1976	Lambert & Peppard 1993	
		Senge 1992	Huysman et al. 1994	
		Zollo & Winter 2002	Prieto & Easterby-Smith 2006	
Linguistics	Generative grammar as a formal specification of language	Chomsky 1957, 1966, 1986	Gaskin et al. 2014; Lee et al. 2008; Lyytinen 1985; Shawe-Taylor 1987; Truex & Baskerville 1998	5
Organizational routines	Organizational routines as generative systems capable to produce a variety of performances depending on experiences and context	Feldman & Pentland 2003; Pentland & Feldman 2008; Pentland & Rueter 1994	Beynon-Davies 2010; Iannacci 2014; Kutsch et al. 2013; Robey et al. 2013	4
Complexity theories	Generative relationships; generativity of complex objects; generative process of self-organization	Lane & Maxfield 1996	McBride 2005	3
		Law & Singleton 2005	Whitley & Darking 2006	
			Merali 2006	
Institutional theories	Generative regime; institutionalization as generative process		Reimers 1996	2
		Zucker & Darby 2005	Baptista 2009	
Information systems design	Generative fit of IS designed to enhance generative capacity of humans		Avital & Te'eni 2009	2
		Avital & Te'eni 2009	Majchrzak & Malhotra 2013	
Design ethnography	Generative in the sense of creating a particular solution	Otto & Smith 2013	Baskerville & Myers 2015	1
Hermeneutic cycle	Generative structures as collective meaning	Klein & Myers 1999	Njenga & Brown 2012	1
Psychology	Generative learning process	Wittrock 1974	Kwok et al. 2002	1
Public values	Generative perspective	Davis & West 2009	Pang et al. 2014	1

Table 3. Same term, different things: meanings of generativity in identified articles

5 THE GENERATIVE CAPACITY OF DIGITAL ARTIFACTS

5.1 Approaching the scholarly discourses related to generativity from two different angles

We already introduced Zittrain's conceptualization of generativity as the capacity of a technology or a system to be malleable by diverse groups of actors in unanticipated ways. We posited that the particular characteristics of digital artifacts might enable or facilitate generativity in myriad ways. In the reviewed literature sample, the majority of articles focused on just two types of digital artifacts, namely *digital platforms* and *digital infrastructures*, while three papers (or about 20%) addressed *digital artifacts in general*, see also Table 4 below.

Digital artifact type	Themes	Approach	Articles	#
Digital infrastructures *Shared, open, heterogeneous, and evolving system consisting of digital artifacts and their user, operations, and design communities*	Dynamic complexity; bootstrapping; installed base; paradox of change and control; procrastination principle; inscription and interpretation	Conceptual	Hanseth & Lyytinen 2010; Tilson et al. 2010	2
		Empirical	Grisot et al. 2014; Henningsson & Henriksen 2011; Racherla & Mandviwalla 2013	3
Digital platforms *Extensible framework that addresses a family of generic functionalities meeting the needs of heterogeneous user communities*	platform-controlling actor and third-party actors; ecosystem; boundary resources; emergent tensions and dialectic resolution; modular-layered architecture	Conceptual	Lusch & Nambisan 2015; Yoo et al. 2010	2
		Empirical	Bergvall-Kåreborn & Howcroft 2014; Eaton et al. 2015; Ghazawneh & Henfridsson 2013; Selander et al. 2013	4
Digital artifacts (in general) *Object created by and composed of digital technology and the outcome of coordinated human action*	Hierarchy of parts and network of patterns; digital artifacts as operant resources	Conceptual	Nambisan 2013; Yoo 2013	2
		Empirical	Henfridsson et al. 2014	1

Table 4. Types of digital artifacts and themes discussed in the literature review sample

Before turning to a description of the identified artifact types and the ways in which they have been suggested to unlock or foster innovation through their generative capacity, it is worth exploring established themes to which IS researchers related the nascent generativity concept. Following an evaluation of the 14 sample articles listed above, Table 5 below provides an overview of the scholarly discourses with which the generativity concept has been commonly associated, and of the literature base jointly regarded as salient to these discussions. This gives us a slightly different angle for reviewing the field of generativity.

As could be expected from the results summarized in Table 4 above, we find the two discourses on *digital infrastructures* and network effects related to them, as well as on *digital platforms* and the ecosystems those create. Furthermore, the role of digital artifacts to enable and facilitate *innovation* has been commonly discussed, providing a cue that the outcome of generativity–that is, unanticipated change by diverse groups of actors–is thought to be innovation. The fourth dominating scholarly discourse deals with decomposition of complex systems and *modularity*, suggesting that any discussion about generativity should be conducted with consideration of the rich history of modularity in IS research (cf. Yoo 2013). Finally, a few articles established links to structuration theory and also to organizational agility. Because we do not aim for exhaustive review of the literature base with this paper, we chose to disregard these two themes. Nevertheless we acknowledge their relevance to generativity research, as exemplified by investigations of Woodard & Clemons (2014) and Kretzer et al. (2014). Hence, in what follows and drawing from the reviewed literature base, we describe the four dominating strands which we identified and their association with generativity.

Scholarly discourse	Aspects discussed	Referenced literature	Sum of citations
Attributes and dynamics of digital infrastructures, network effects and installed base	Digital infrastructures are socio-technical systems; modern digital infrastructures span several organizations and may have global reach; evolution and innovation is non-linear, typically initiated to suit a specific local context and thus uncontrollable top-down; infrastructures might deviate from planned purpose over time; early standard-setting is central to fast growth; cumulative evolution leads to network effects; evolution of infrastructure is both enabled and constrained by installed base; intelligence at the endpoints, not the center of an infrastructure	Benkler 2006; Ciborra 2000; Shapiro & Varian 1999; Star & Ruhleder 1996	19
Attributes and dynamics of digital platforms and ecosystems	Ecosystems consist of a set of relatively stable components (digital platform) and another set of evolving components that allow variation and innovation (third-party contributions); interfaces set standards for how to interact with the platform; platforms lower barrier of entry and foster experimentation; digital platforms pose issues of power and autonomy	Baldwin & Woodard 2009; Boudreau 2012; Tiwana et al. 2010	18
Digital artifacts as enablers and facilitators of innovation	Democratization of innovation as consequence of pervasive digitization; recombination of existing resources drives innovation; heterogeneous groups of actors provide varied innovation capability and knowledge resources	Arthur 2009; Boland et al. 2007; Hippel 2005; Yoo 2010	20
Decomposition of complex systems, logic of modularity	Isomorphism of product design logic and organizational structure; decomposition into design hierarchies; modularity as organizing logic for complex systems; stable interfaces enable concurrent design of sub-components and reduce dependency	Baldwin & Clark 2000; Clark 1985; Simon 1996	14
Structuration theory applied to technology	Flexible interpretation of digital artifacts by their users; digital artifacts are both shaped by their context and shape their context	Orlikowski 1992	4
IT-enabled organizational agility	Digital artifacts generate real options which facilitate change; malleability of digital artifacts enable organizational agility	Sambamurthy et al. 2003	4

Table 5. Scholarly discourses commonly discussed in conjunction with generativity

5.2 Digital infrastructures

In the literature, *digital infrastructures* (or *information infrastructures*, as they are more commonly called) are regarded as socio-technical systems, hence they consist of more than technology components (Ciborra 2000; Star & Ruhleder 1996). They are networked systems that span beyond and across individual organizations and may gain global reach (Ciborra 2000). Hanseth & Lyytinen (2010: p.4) define these infrastructures, of which the internet is a prime exemplar, as follows:

"A shared, open (and unbounded), heterogeneous and evolving socio-technical system (...) consisting of a set of IT capabilities and their user, operations and design communities. (...) Structurally a (digital infrastructure) is recursively composed of other infrastructures, platforms, application and IT capabilities. (...) Control is distributed and episodic and an outcome of negotiation and shared agreements. (...) Episodic forms of control determine which groups of designers control which parts or elements of the (digital infrastructure). (...) There are no clear boundaries between those that can design the (infrastructure) and those that may not. (...) The openness (...) implies that during their lifetime the social and technical diversity and heterogeneity of (digital infrastructures) will increase."

Digital infrastructures depend on the active involvement of heterogeneous groups of actors in using, operating, and designing them. Zittrain captures this dependency as *"invitation to outside contribution"* (2008: p.90) and sheds light to the self-reinforcing dynamics of active infrastructures: the more actors contribute in using, operating, and designing, the greater the generative capacity of this system becomes, which in turn will lead to more, and more varied unanticipated evolution and innovation. Hanseth & Lyytinen (2010) call this central aspect *dynamic complexity*, which the authors regard to be conceptually close to generativity. Evolution and innovation of digital infrastructures is non-linear, typically initiated to suit specific needs of a local group of actors (Star & Ruhleder 1996), which is why infrastructures cannot be controlled top-down, and over time their development paths might deviate from originally planned purposes (Ciborra 2000). Given the importance of attracting actors to participate in a digital infrastructure, scholars explored key mechanisms how to achieve this goal. One such mechanism is *bootstrapping*, the tactic of attracting early users by making the infrastructure immediately useful for their specific needs, while deliberately neglecting long-term issues such as architectural robustness if so required (Grisot et al. 2014; Hanseth & Aanestad 2003; Hanseth & Lyytinen 2010). Bootstrapping can be regarded as an entrepreneurial approach to making the most out of limited available resources and letting serendipitous design activity ultimately lead to creative innovation (cf. Fisher 2012; Ries 2011).

The self-reinforcing dynamics of digital infrastructures can only unfold if there is a sufficiently large and structurally stable *installed base*, that is all the individual elements and their connections making up the digital infrastructure (Star & Ruhleder 1996; Tilson et al. 2010). Without stability in the installed base extensions and additions are not possible, hence setting a standard early on is indispensable for continued growth of such systems and the generation of network effects (cf. Shapiro & Varian 1999: chapter 8). Setting a standard, however, may dampen the possibility for emergent design, may create unwanted path dependencies, and thus may limit creative innovation (Racherla & Mandviwalla 2013; Star & Ruhleder 1996), a tension which Tilson et al. (2010) call the *paradox of change and control*.

By discussing the design of the internet, in particular its enforcement of the internet protocol (IP) as the sole standard for data transmission while leaving myriad options on all other architectural layers, Zittrain (2008) suggests the *procrastination principle* as one way to overcome this tension: the elements on which all actors rely should not solve design problems that affect just some of them. This concept resembles Benkler's (2006) argument of instilling intelligence at the endpoints, not the center of an infrastructure. Henningsson & Henriksen (2011) pick up these ideas to conclude that a digital infrastructure should *inscribe* just a few commonly accepted regulations, but otherwise be open to *interpretation*, that is ambiguity and emergent evolution in its design and usage. This openness is consistently named a key attribute of digital infrastructures (Grisot et al. 2014; Hanseth & Lyytinen 2010; Henningsson & Henriksen 2011; Racherla & Mandviwalla 2013; Tilson et al. 2010) and can be related to earlier ideas of tinkering/bricolage (Ciborra 1991) and improvisation (Orlikowski 1996).

5.3 Digital platforms

Again, we refer to Hanseth & Lyytinen (2010: p.4) and conceptualize *digital platforms* as follows:

"Platform designs (...) organize IT capabilities into frameworks allowing the software to address a family of generic functional specifications that meet the needs of multiple, heterogeneous and growing user communities. (...) Platforms typically grow in complexity as designers take into account heterogeneous user needs while maintaining backward compatibility and horizontal compatibility across different combinations of capabilities. Therefore, many platforms, originally conceived as limited sets of IT capabilities, obtain later emergent features; they start growing in seemingly unlimited fashion and serve unexpected users (…) generating exponentially growing technical and social complexity."

The boundaries between a platform and an infrastructure are fluid. For instance, what Grisot et al. (2014) call an *infrastructure* in their article might also fit above definition of a platform. For the purpose of this paper, and in line with Hanseth & Lyytinen (2010), we delineate the former from the latter by demanding a digital platform to be controlled by one single actor, while control of a digital infrastructure is distributed across many actors. Identifying a *platform-controlling actor* consequently introduces *third-party actors* which leverage the platform for pursuing their own goals. A relatively stable, centrally controlled digital platform in conjunction with the variety of evolving applications and services provided by third-party actors compounds the overall platform *ecosystem* (Baldwin & Woodard 2009; Boudreau 2012; Lusch & Nambisan 2015; Tiwana et al. 2010).

Upon first thought it might seem odd to contemplate the generative capacity of a system whose central element–the digital platform–is controlled by one single actor. However, several researchers showed that nurturing unexpected change brought by heterogeneous groups of actors ultimately serves the interest of all parties: the platform-controlling actor needs an attractive ecosystem of applications and services in order to keep up effectively with competing ecosystems; and third-party actors want to distribute their applications and offer their services within a thriving ecosystem because they can reach broader audiences than they otherwise could (Bergvall-Kåreborn & Howcroft 2014; Eaton et al. 2015; Ghazawneh & Henfridsson 2013). Hence, the platform-controlling actor has a strong incentive to design and keep its platform as open and malleable as possible (Eaton et al. 2015; Ghazawneh & Henfridsson 2013), while third-party actors engage in ecosystems from which they can expect to profit most (Bergvall-Kåreborn & Howcroft 2014; Selander et al. 2013).

Still, the platform holder exerts considerable control, mainly through software tools and accompanying regulations that expose the digital platform to third-party actors, that is through platform *boundary resources* such as APIs and associated governance (Ghazawneh & Henfridsson 2013; Tiwana et al. 2010). Designing, maintaining, and evolving boundary resources confronts the platform-controlling actor with challenges similar to the paradox of change and control mentioned in the discussion on digital infrastructures (Baldwin & Woodard 2009; Tiwana et al. 2010). What is more, it is likely that inventive third-party actors will utilize boundary resources in unanticipated ways or that they will create their own, unauthorized boundary resources to exploit platform features that were not intended to be accessible. For instance, when Apple introduced its iPhone device and accompanying digital platform, third-party actors soon found ways to *jailbreak* it, thus creating a way to open up the platform for outside development (Eaton et al. 2015; Ghazawneh & Henfridsson 2013). Both Eaton et al. (2015) and Ghazawneh & Henfridsson (2013) argue that permanent loops of *emerging tensions* between platform-controlling actor and third-party actors and their *dialectic resolution* in the interest of all parties keep a platform and the broader ecosystem relevant and lead to unexpected, creative, and innovative outcomes.

Some researchers explored aspects of what Hippel (2005) calls the *democratization of innovation*. Digital platforms empower individuals or very small organizations to innovate, in that they provide powerful means to come up with new things and offer a large audience for experimentation (Boudreau 2012). Eaton et al. (2015) and Bergvall-Kåreborn & Howcroft (2014) remark that such democratization has only become possible because there are a few large and very resourceful companies that design and nurture digital platforms, pointing to apparent imbalances on both ends of the ecosystem, which might lead to unilateral abuse of power. The authors also observe that even among third-party actors, discrepancies with regard to their size, capabilities, and other facets are tremendous. This accentuates the heterogeneity of actors so central to generativity, but also indicates that there will be winners and losers within each ecosystem (Tiwana et al. 2010). Selander et al. (2013) emphasize that even large organizations have good reasons to participate in digital platforms, mostly in order to gain access to capabilities and other resources which they could hardly obtain otherwise.

Finally, Selander et al. (2013) and Yoo et al. (2010) discuss why large organizations might be motivated to design and nurture digital platforms in the first place. They suggest that the *modular-layered architecture* of digital technology unlocks vast possibilities for resources recombination and innovation (cf. Arthur 2009; Lusch & Nambisan 2015). Due to the separation of services from devices–through the possibility to reprogram and repurpose digital artifacts–and the separation of content from the transport medium–through digitization of data–the authors argue that it makes sense to connect heterogeneous actors via a common platform, even accepting the tensions that arise from conflicting agendas: the joint innovative outcomes within an ecosystem will most likely be superior in quality and quantity than what an organization would be able to achieve in isolation (cf. Chesbrough 2003).

5.4 Digital artifacts, innovation, and modularity

Interestingly, there is no widely accepted definition of a *digital artifact*, and indeed it may be doubted that this term is useful at all (Alter 2015). Nevertheless and for the limited purpose of providing an overview of past research on generativity we suggest the following working definition, borrowed from

Orlikowski's (1992) discussion of the technology concept and combined with the conceptualization of distinct digital artifact attributes (Kallinikos et al. 2013):

A digital artifact is an object created by and composed of digital technology and the outcome of coordinated human action. It is created and changed by human actors, but it is also used by humans to accomplish some action. Digital artifacts fundamentally differ from physical artifacts in that they are interactive, editable, reprogrammable, distributed, modular, granular, and reflexive.

Researchers arguing why systems interspersed with digital artifacts have greater generative capacity and produce more innovative outcomes than systems consisting solely of physical artifacts highlight how the first differ from the latter. Henfridsson et al. (2014) focus on the two aspects of reprogrammability and negligent marginal cost of replication and suggest two architectural logics for the physical and digital realm, respectively: a physical artifact is organized in a *hierarchy of parts* to cope with complexity in design and production, but at the cost of fixed boundaries. Digital artifacts however profit from a *network of patterns* approach, in which design patterns are combined and applied to a specific context. By changing the context and adapting the design accordingly, digital artifacts can be repurposed or their functionality can be enhanced. Arthur (2009) reasons that the extent to which existing resources can be readily recombined drives innovation, and that digital artifacts are catalysts of innovation. Nambisan (2013) spins this thought further and argues that in principle digital artifacts can be *operant resources* and trigger innovation on their own, through seeking variation and recombination autonomously. This idea, however, will need further reconciliation with the socio-technical tradition of IS research. For instance, Boland et al. (2007) highlight that it is not technology which drives innovation, but rather its accessibility to heterogeneous groups of actors, which employ their varied capabilities and come up with innovative results. This train of thought is very close to the reasoning of Zittrain (2008), who regards *participation as input* to generativity and *innovation as its output*.

Following the isomorphism argument (Baldwin & Clark 2000), Henfridsson et al. (2014) posit that an organization that designs and produces physical artifacts will be structured along hierarchical components, whereas an organization dealing with digital artifacts will be structured along functional patterns. On similar terms, Yoo (2013) argues that organizations cannot leverage the full potential of digital artifacts by sticking to the logic of modularity and the organizational implications it entails. The author suggests that portraying digital artifacts as parts of generative systems accentuates their capacity to enable emergent change through variation and recombination. Yoo's propositions are in their infancy and will require further clarification in light of the thick research threads around modularity. Ever since the characterization of complex systems as *"ones made up of a large number of parts interacting in a nonsimple way"* (Simon 1962: p.468), their decomposition into *design hierarchies* has been discussed extensively (Baldwin & Clark 2000; Clark 1985; Simon 1996). This discourse led to ideas of *modularity* as organizing logic for complex systems and of stable interfaces enabling concurrent design of sub-components (Baldwin & Clark 2000), and left myriad traces in IS/IT research, for instance *service-oriented architecture* (Erl 2005) and the *modular-layered architecture* proposed by Yoo et al. (2010).

6 CONCLUSION AND FURTHER RESEARCH

With this contribution we set out to describe how Zittrain's generativity concept has been brought into IS research, and in particular in relation to which established scholarly discourses the emerging topic has been discussed. To this end, we first clarified terminological issues and identified a broad range of generativity concepts from 52 articles published in leading IS journals. For the subsequent analysis we focused on Zittrain's conceptualization of generativity as the malleability of technologies and systems by heterogeneous groups of actors with unanticipated outcomes. From an initial, illustrative analysis of how the distinct attributes of digital artifacts may be conducive to the generative capacity of socio-technical systems in which they operate, we concluded that myriad types of artifacts may instill generativity. However, we found that the reviewed sample of 14 articles concentrated on just two types of digital artifacts, namely digital infrastructures and digital platforms. Besides these main strands we detected that generative systems were regularly discussed as means to lead towards innovation, brought by heterogeneous groups of actors. Finally, we identified that discussions of generativity were commonly held in light of the rich intellectual tradition pertaining complex systems and the logic of modularity. Overall, we regard this paper as a contribution to generativity research as sketched by Tilson et al. (2010), Yoo et al. (2010), and Yoo (2013). When a concept from a different scholarly field is adopted, it is important that we first gain a clear grasp of the terminology, the phenomenon, and the context in which it is discussed before setting out to conduct further research.

Before highlighting possible further research, we would like to acknowledge the main limitation of this contribution, namely its lack of exhaustiveness with regard to the reviewed literature. We confined ourselves to articles published in leading IS journals, leaving out many interesting papers. For instance, Zhang et al. (2014) outlined how the transferability characteristic of generative systems–which the authors call *generative diffusion*–can be explored in the context of open source software development. There are many more relevant articles available, as a database search will reveal. Nevertheless we believe that despite the self-imposed limitation this paper still yields considerable value. First, articles published in the leading IS outlets are influential in shaping overall research in the field (Lowry et al. 2013). And second, it is likely that scholars interested in the state of the art of generativity research within the IS community will first seek to identify exactly those articles which we selected and described in this review. Still, we caution the reader to consider this major limitation.

Turning to possible avenues for further research, the results of this review article draw attention to four topics in particular that could stimulate worthwhile research. First, we do not understand sufficiently well the overlaps and differences of modularity and generativity. Yoo (2013) put this challenge into the limelight, and prior research regularly discussed both concepts in conjunction. What are the parts which we can transfer to generativity, how does generativity really differ and how does it lead to different results? These are all questions yet to be answered, but first results indicate that there can be fruitful cross-pollination and that the logics of modularity and generativity may lead to different organizational regimes (Henfridsson et al. 2014; Lee & Berente 2012; Svahn & Henfridsson 2012).

Second, the variety of examined types of digital artifacts might be expanded. Prior research discussed the generative capacity of digital infrastructures and digital platforms only. In our introductory section we argued that it is the distinct characteristics of digital artifacts (Kallinikos et al. 2013) that may instill generativity in a system, hence there should be other types of digital artifacts besides infrastructures and platforms to which the generativity concept can be valuably applied. One way forward might be the examination of the attributes of digital artifacts (e.g., reprogrammability, distributedness) and how they are favorable with regard to the attributes of generativity (e.g., adaptability, transferability). We refer to the research of Henfridsson et al. (2014) and Zhang et al. (2014) for exemplary steps onto this path.

Third, in light of the reviewed literature we were not very precise in delineating digital artifacts from socio-technical systems. On the one hand, we posited that digital artifacts as elements of a system may instill generativity. On the other hand, we gave definitions of digital infrastructures, digital platforms, and digital artifacts in general that highlighted their socio-technical nature. This lack of conceptual clarity might be tackled by expressing digital artifacts and their generative capacity with the vocabulary of sociomateriality (Leonardi 2012; Orlikowski 2000). For instance, recent research from Woodard & Clemons (2014) already points into this direction.

And fourth, throughout this paper we discussed generativity as means towards innovation. However, *unanticipated outcomes* do not have to be innovations, there might be other worthwhile ends to be considered. For example, generative capacity might be exploited for organizational agility purposes, that is to better sense environmental change and respond to it (Goldman et al. 1995; Sambamurthy et al. 2003). Some traces towards alternative ends of generativity can already be found in IS research (e.g., Kretzer et al. 2014; Svahn & Henfridsson 2012).

To conclude, IS research on generativity has just begun. From reviewing the literature we concur with Yoo (2013) to believe that the intellectual tradition of IS research combined with the novel lens of generativity can bring much to the table in providing valuable insights to information and technology management, but also in advancing our knowledge of socio-technical systems in a digitized world.

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